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ENVIRONMENTAL EFFECTS of the OPERATION of SULFUR EXTRACTION GAS PLANTS

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BY

Dr. R.F. KLEMM

CONSULTANT

SUBMITTED TO

Alberta

ENVIRONMENT CONSERVATION AUTHORITY

SEPTEMBER, 1972

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FOREWORD

This report on the Environmental Effects of Sulfur Extraction Gas Plants in Alberta is made available to the public by the Environment Conservation Authority for the purposes of the public hearings. The Authority does not take the position of necessarily agreeing or disagreeing with any or all of the statements in the report. It is expected that participants in the hearings will find the report meaningful in providing general background information, that they will amplify on portions of the report, and that they will also introduce new information.

The report has been prepared by Dr. Roger F. Klemm, of the Research Council of Alberta, whose time was made available as a consultant for the period of the task. The material in this report has been released with the approval of the Government of Alberta. Dr. Klemm will also devote additional time to the subject prior to and during the public hearings on Sulfur Extraction Gas Plants.

The Environment Conservation Authority is most appreciative of the arrangement entered into by the Research Council of Alberta whereby Dr. Klemm has been released from his normal duties to undertake this project.

Dr. W. R. Trost
Chairman
Environment Conservation Authority

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ACKNOWLEDGEMENT

Approximately two and one-half months were allotted to information gathering. An additional month was spent in bringing the material collected to its present form. This will indicate the time constraint imposed upon the depth to which any given subject could be treated.

During the preparation of the report time and information in many forms was solicited from numerous members of the community at large as well as experts in government, industry and labour. So as not to overlook even the slightest contributor the consultant wishes to offer his whole-hearted appreciation and thanks to this large group of interested citizens, all of whom unfortunately will have to pass into anonymity as individuals at this time. Chapter IV was prepared with the assistance of the staff of the Department of the Environment.

The concern and assistance of all members and staff of the Environment Conservation Authority merit particular commendation, especially Dr. W.R. MacDonald who provided the important liaison between the consultant and the sources of information cited above.

R. F. Klemm
August 15, 1972

DOCUMENTATION OF REFERENCES

All original material referenced in the present report has been placed on file at the offices of the Environment Conservation Authority in Edmonton. In addition, a file of more general information relating to the environmental aspects of sulfur extraction processes will be available in the offices of the Authority for interested parties.

Interdepartmental memorandums in Government are considered as confidential material unless released by Ministerial approval.

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INTRODUCTION

This resume of the sour gas industry and its attendant impact upon the province of Alberta has been prepared under the sponsorship of the Alberta Environment Conservation Authority. Its intended purpose was to "outline the present situation in Alberta concerning sulfur extraction plants and to describe the present technology employed in sulfur extraction".

In treating this subject it was further specified that such a report should enter into a generalized discussion of the following items as they pertain to sour gas handling.

1. Outline the history of sulfur extraction in Alberta.
2. Indicate present plants, output, economics, etc.
3. Identify benefits that are derived directly from the industry in terms of employment, income with respect to the general economy.
4. Review various processes used in recovery.
5. Discuss overall plant operation, transmission of the gases to the plants, and methods of stockpiling sulfur.
6. Discuss the uses of sulfur.
7. Discuss the transportation of sulfur.
8. Discuss problems of plants: corrosive gases, effluents, toxic chemicals.
9. Discuss emissions, limits, and the means of attaining these limits.
10. Discuss measuring techniques for air pollution, determination of stack heights, monitoring techniques and present practices in Alberta.
11. Discuss meteorological dispersal of pollutants and the resultant return of these pollutants to earth.
12. Discuss the effects of sulfur dioxide, hydrogen sulfide, and other toxic compounds on humans.
13. Discuss the effects of the above compounds on animals and plants.
14. Discuss the effects, etc. of these compounds known to have occurred in Alberta.
15. Discuss current legislation and regulations applicable to the area of environmental control, particularly paying attention

to those affecting sulfur extraction plants.

16. Mention some questions that may be asked concerning the operation limits, etc., of sulfur recovery plants in Alberta.

While the above listing would seem to be all-encompassing, it was not intended that these issues were to be taken as the absolute boundaries for the presentation at hand. Thus, although the format of the appended report follows closely the guidelines as designated, certain peripheral themes have been suggested as material was collected, as well as from discussions with the many people who have contributed to this document in one way or another. Such themes have been discussed individually and almost parenthetically, in whatever context the subject could be introduced most expediently.

It is to be hoped that the information contained in this report will stimulate amplification and more thorough treatment in the individual presentations upon which public participation so intimately depends. In like manner, it is to be expected that, again through public cooperation, attention will also be drawn to relevant areas which this report has not considered.

PART 1

HISTORY AND ECONOMICS

1.1 Background

At the outset it seems advisable to emphasize that a discussion of sour gas processing plants cannot be easily considered without at least cursory reference to the natural gas industry *in toto*. Indeed, although the terms of reference for this document apply strictly to the environmental effects of sour gas processing facilities, in discussing these effects at the well-site and throughout the gathering stages the impact upon the surroundings is, generally speaking, common to the entire gas industry. Thus almost all hydrocarbons from underground formations contain some sulfur, predominantly in the form of hydrogen sulfide (H_2S). Hydrogen sulfide is an acidic gas; hence the term "sour gas" will be applied to natural gas containing this constituent in excess of an amount specified as the maximum allowable for home consumption of natural gas. Any gas which is sour must be "sweetened" to bring it within the limits prescribed for hydrogen sulfide content; it is then a "sweet gas". Elemental sulfur obtained from the hydrogen sulfide is the by-product of the sweetening process of natural gas and depending upon economic factors may, at times, be thought of as an involuntary by-product of the natural gas industry. The point to be stressed is that the rate of sulfur production and its attendant consequences can be intimately associated with the demand for natural gas, a demand that can only increase in the foreseeable future.

The association of sulfur with natural gas is also the source of a certain amount of confusion especially when one attempts to extricate the economic and socio-political impact of sour gas facilities from those of the overall gas and oil industry. Consequently it must be understood that certain of the statistics and information to follow represent the gas industry as a whole while other data have fortunately been made available for sour gas processing alone. It is hoped the impact of the natural gas industry and its accompanying sulfur production upon the Alberta environment will be more evident as a result of the following report.

The purpose of this introductory section is to view the subject under consideration from its historic and economic position. To this end a number of figures and tables is inevitable. It is also unavoidable that they may disagree in detail among themslevcs or with other quoted data. If attention is directed at orders of magnitude and the changes in a given set of figures with time a reasonable perspective will be forthcoming regarding the place of the sulfur extraction industry in the economy of the province.

In terms of direct employment at gas processing plants the numbers are small - perhaps five thousand employees among some 150 plants. But this figure also completely ignores the very sizeable secondary employment generated by the oil and gas industry.

1.2 Early History and Conservation Measures

Turner Valley holds a firm and monumental place in Alberta history and legend as the site of what was hoped would be the jumping off point for Alberta's economy. The Turner Valley field had already been delineated in 1914. However, it wasn't until 1924 that Royalite No. 4 penetrated the main resevoir of the Turner Valley field. The result was a product high in natural gasoline, an item in considerable demand at that time. Associated natural gas for the most part was unwanted and flared after passing through well-site separators. As the demand for natural gasoline declined and that for natural gas increased, Royalite decided to build a central plant to process the gas that previously had passed through these well-site separators. Thus, the original Turner Valley plant was established in 1933. At this time a considerable impact upon the environment was tolerated (and indeed this was so until very recently), for no sulfur was recovered at the original plant; it probably vented in the order of 200 long tons per day (LTD) of sulfur to the atmosphere as sulfur dioxide (SO_2).

Crude oil production showed further expansions throughout the 1930's and '40's. Even in the mid-1950's apart from facilities at Acheson, Bonnie Glen, Redwater and Turner Valley, the natural gas produced in conjunction with this crude oil was burned off to the atmosphere in flare stacks. Of course, no summary would be complete without mention of the important discoveries at Devon-Leduc 1947-1951.

In these formative years the industry was small, as was the population of the province. Hence, there was little concern for the effect of the industry upon the environment. The Alberta environment didn't generate the social concern it does today. This was partly because the early gas was relatively sweet and had a negligible amount of salt water associated with it. This formation water was occasionally allowed to run off around the well site with detrimental effect to the vegetation lasting for years. What little control the Energy Resources Conservation Board (then the Oil and Gas Conservation Board)*exercised at that time (1930-'47) was limited by statute to the conservation of oil and natural gas. Naturally as more wells were drilled, pollution problems escalated. With the first sour gas wells at Jumping Pound in 1951 came an increased awareness of a possible air pollution problem. In anticipation of this problem and also as a conservation measure a one-stage Claus sulfur recovery unit of 80% efficiency was installed at the Jumping Pound plant for the recovery of 30 long tons per day (LTD) of sulfur from a designed maximum input of 35 million cubic feet per day (MMCFD) of raw gas.

1.3 History: 1957 to the Present

By 1957-'58 pipeline completions enabled Alberta oil and gas to enter Ontario and U.S. markets. This had a tremendous impact on sulfur production in the following way. While the Shell Jumping Pound plant was based on 3-4% hydrogen sulfide in the raw feed stock, the expanded markets for natural gas and sulfur made it feasible in 1959 and 1961, for the Okotoks and Petrogas Crossfield plants to process raw gas containing 33-34% hydrogen sulfide. Under these conditions the percentage increase in sulfur recovered was greater than the percentage increase of associated marketable natural gas. The result was that sulfur production increased from 45,000 long tons per year in 1957 to 1.3 million long tons per year in 1963 and additionally at the rate of 10% per

---

* The Petroleum and Natural Gas Conservation Board was established in 1938.

year between 1963 and the beginning of 1967. By the end of 1967 sulfur production stood at 2.2 million long tons per year, almost double the 1963 output. A nearly 30% increase of sulfur production in 1967 was due principally to the commissioning of the Petrogas Plant at Balzac and the Canadian Superior Plant at Harmattan, the latter processing raw gas containing 52% hydrogen sulfide.

A further upsurge in the U.S. economy, coupled with new pipeline outlets to the U.S. midwest, plus increasing concern with pollution abatement in Canada, pushed sulfur production over 3 million long tons per year in 1968 and up to 3.8 million in 1969. By the end of 1971 sulfur production reached 4.5 million tons per year. These data are summarized in Figure 1.1.

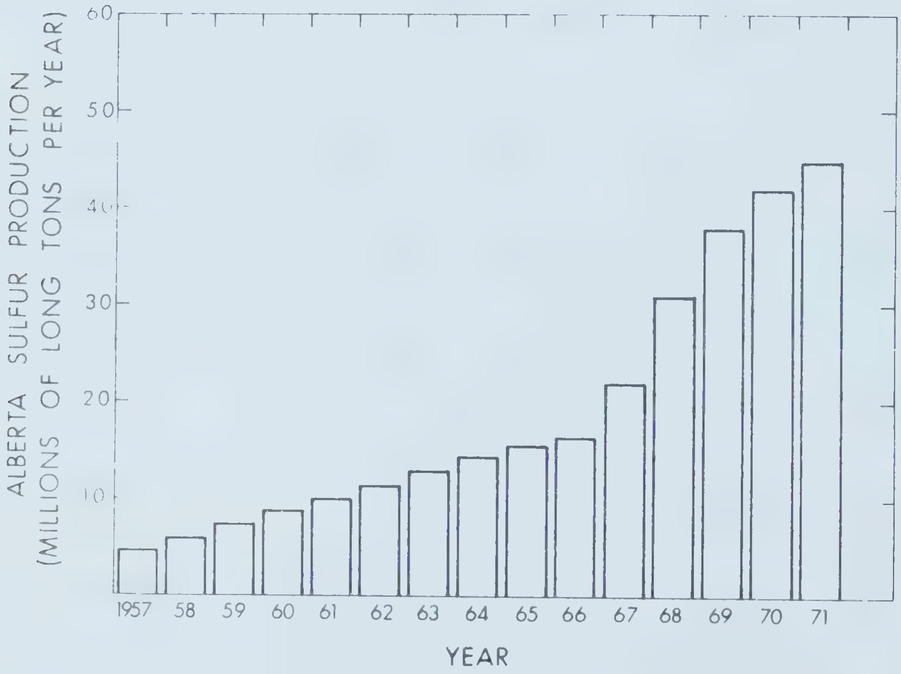

FIGURE 1.1 - ALBERTA SULFUR PRODUCTION IN MILLIONS OF LONG TONS PER YEAR

From three plants processing natural gas in 1947 the industry has expanded to a present 152 plants sixty-seven of which process sour gas (45% of the entire industry). These sixty-seven plants are shown in Figure 1.2. Of these sixty-seven sour gas plants, forty-two are required to recover elemental sulfur as a by-product. The twenty-five plants not required to recover sulfur burn their hydrogen sulfide and release the sulfur to the atmosphere as sulfur dioxide. As of March, 1972, the 152 plants had a total design capacity for processing 12,000 million cubic feet per day of raw gas gathered through 32,000 miles of pipe. From this raw gas 10,000 million cubic feet per day of natural gas could be recovered. In addition these plants were capable of producing 116,000 barrels per day (B/D) of propane, 70,500 barrels per day of butanes, 256,000 barrels per day of pentanes plus and over 24,000 long tons per day of sulfur at an overall average recovery efficiency of 95%.

Here it seems expedient to comment further upon the presentation of the statistics so as to advise the reader regarding figures based upon "designed maximum daily capacity". Maximum plant through-put is never sustained throughout the year, as gas sales are subject to seasonal and in some instances to daily variations, normally being higher in the winter when the demand for natural gas is greater.

1.4 Industry Expenditures in the Province

Totalled from its inception the natural gas industry represents a physical capital investment value of $800 million to the province (Energy Resources Control Board statistic). This is a figure often quoted without comment. While it certainly is impressive as it stands it is also meaningless without that further comment. First of all, as an accumulated figure it represents the sum of all the original plant investment costs plus additions in the current dollars. This is not to deny the sub-contracts let to Canadian and Alberta firms, however. Certainly this job multiplier effect of the sour

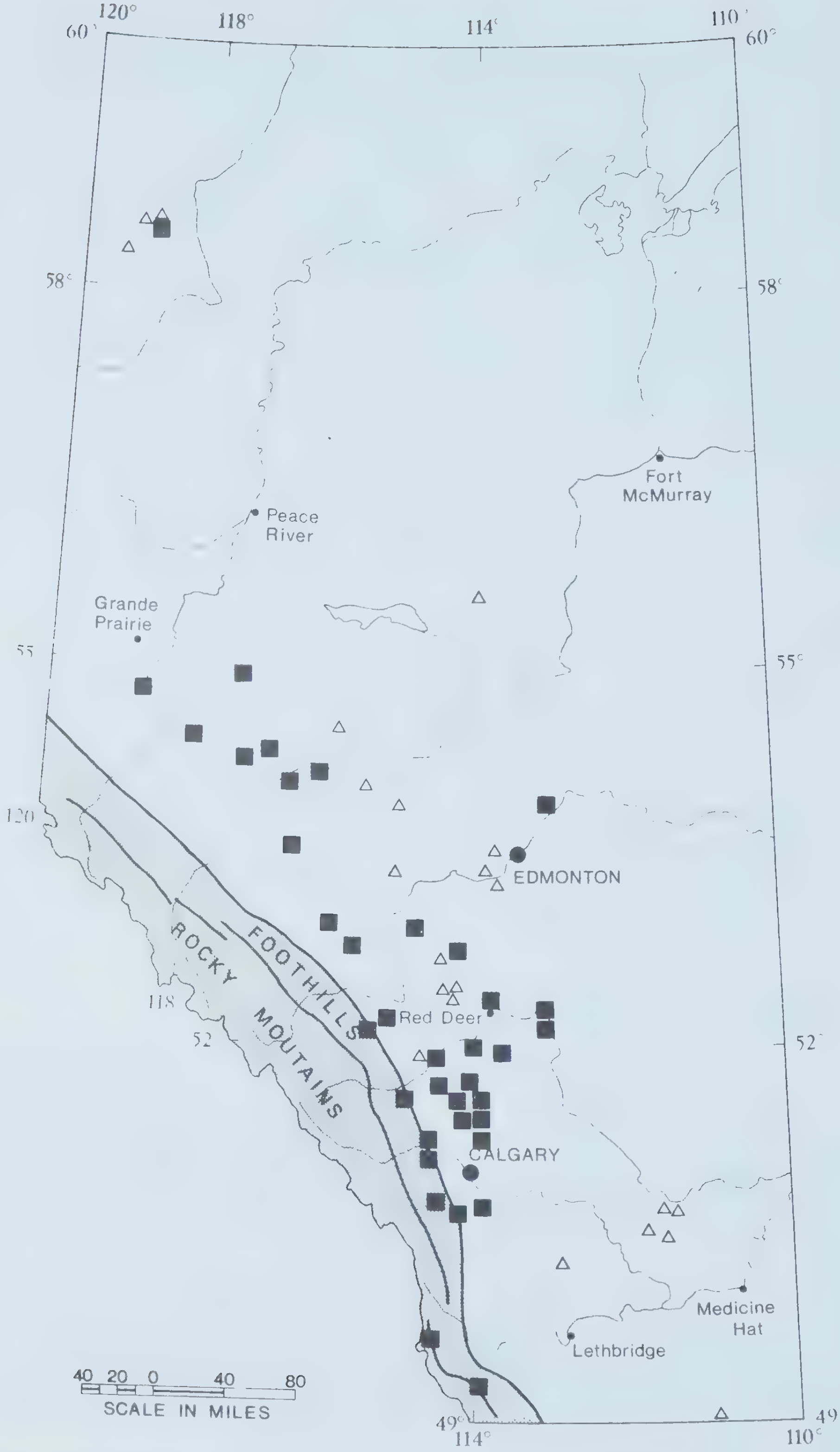

FIGURE 1.2 - LOCATION OF SULFUR EXTRACTION GAS PLANTS IN ALBERTA.

■ Sulfur producing plants

△ Sulfur extraction plants which do not recover sulfur gas industry on our economy has been of inestimable value.

A break-down of other relevant industry expenditures and payments for 1970 and 1972 is given in Table 1.1 as obtained from Oilweek, February 21, 1972.

TABLE 1.1

BREAKDOWN OF INDUSTRY EXPENDITURES IN ALBERTA, MILLIONS OF DOLLARS

	1972 (Predicted)	1970
Exploration	175	163.9
Development	80	63.6
Land	110	106.6
Production Facilities	100	90.3
Production Costs	240	186.7
Gas Plants	105.5	165.7
Royalties	220	156.9
Other	100	89.3
Total	1,130.5	1,023.0

It is no exaggeration to point out that the growth of the province since 1947 has essentially paralleled that of the oil and gas industry.

1.5 Alberta Production in a World-Wide Context

The above statistics take an even broader significance to Albertans when considered in their Canadian and world-wide context. Figures for the past fifteen years show that the primary sources of sulfur in Canada and the world have shifted drastically as a result of the sulfur output associated with the processing of sour gas. Canada changed from a net importer of sulfur in 1960 to become, since 1968, the world's largest exporter of elemental sulfur and in 1971 was second only to the U.S. in total production. As the leading exporter Canada (or more narrowly Alberta, since it is the source of 90% of sulfur exported from Canada) has assumed price influence in this industry, long the perogative of sulfur production in the U.S. based primarily on the Frasch process. Ironically, as a result of intensive marketing efforts and its unique position as a by-product industry, Alberta sulfur can partly be held responsible for the drastic drop in sulfur prices since 1968. Table 1.2 summarized from Oilweek, January 24, 1972, gives the relevant information with the added comment that in July, 1971 a low of $6.41 was being received for a ton of sulfur, f.o.b. Alberta.

TABLE 1.2

VALUE OF CANADIAN SULFUR PRODUCTION

Year	Prodn. (LT)	Sales (LT)	$ Sales Value	$ Price/Ton
1971	4.5 million	2.8 million	21 million	7.50
1970	4.2 million	3.1 million	28 million	8.92
1968	3.0 million	3.3 million	78 million	34.53

While the U.S. is Canada's largest export market (39% of total sulfur sales), the importance of off-shore markets should not be minimized. Sulfur for some of these markets is currently shipped in unitized trains to Vancouver. Transportation costs, particularly for off-shore markets constitute a major factor in the competitive marketing of Alberta sulfur. The latest year for which statistics are available (1970) indicated that loading, transportation and storage costs exceeded the average f.o.b. price to Alberta producers by about one dollar per ton for sulfur marketed off-shore.

1.6 Future Predictions

Obviously the major factor in the world view, as far as Alberta is concerned, is the gap between the supply and demand for sulfur, resulting in rapidly mounting stockpiles and falling prices. The outlook for the future suggests Canada will remain the world's largest exporter; however, world-wide concern over pollution abatement will certainly have its influence in changing somewhat the traditional supply sources.

Anticipating decreasing reserves of natural gas, the National Energy Board announced in November, 1971 that it will not consider future increased export permits for natural gas until domestic needs and supply have been evaluated. The result may be a rise in the price of natural gas and a consequent slackening in demand. Figure 1.3 illustrates these facts in terms of

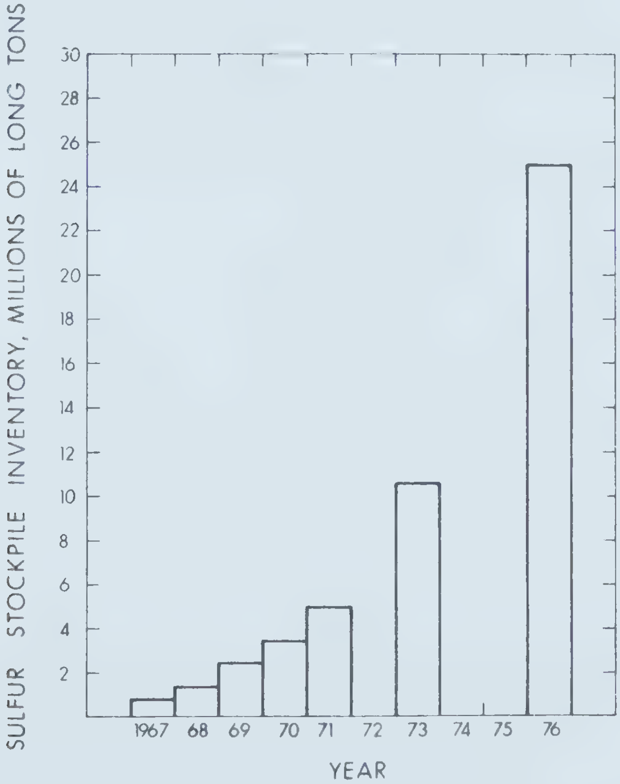

FIGURE 1.3 - ACTUAL AND PROJECTED SULFUR STOCKPILE INVENTORY IN MILLIONS OF LONG TONS (References 7 and 9)

associated sulfur stockpiles. The data include sulfur held at plants, terminals and port facilities. Predictions for the future allow for a 4-5% annual increase in sulfur sales. This annual increase may be compared to the nearly 7% average yearly increase in sales for the late 1960's. Furthermore, it must be pointed out that all predictions of this sort are extremely conditional and should be taken with reservation. They do give an order of magnitude indication of the stockpiling situation.

It is projected that Alberta's share of the sulfur market will likely be on the order of 4 million long tons per year in 1972 which is roughly only one-half of its maximum design capacity. This share may increase to 6 million long tons per year by 1976. Obviously an over-supply is going to exist for some time, given present conditions and projected demands for natural gas.

The value of gas plant construction over the next 3-5 years will probably be less than $100 million simply because no new large fields have been discovered since Ricinus West; and it typically takes four to five years from discovery to bring a plant on stream. Further, the $100 Million will be spent principally in additions and facility upgrading at existing plants rather than construction at new plants.

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PART 2

INTRODUCTION TO PLANT OPERATION

2.1 Structure of the Gas Processing Industry

The structure of the gas industry is peculiar to western Canada. There appears, superficially at least, no high degree of correlation between (a) operating responsibility for a given natural gas processing complex, (b) ownership of the production of the natural gas, liquified petroleum gases (LPG's) or sulfur and (c) the marketing responsibility for the various products. As a consequence various firms may be conducting exploration work on adjoining claim areas and following discovery of a promising petroleum prospect some or all of the companies would commence development work on their own sites with a view to delineating the field. If commercial exploitation seems feasible the field would be "unitized" - all companies (there may be as many as forty) would pool their knowledge of the field and establish a processing unit. The consortium then assigns operating responsibility for the processing unit usually to one of the group of owners. The members usually contribute on the basis of working interests whereby they or their agents dispose of their accredited product, or on the basis of royalty interests, whereby they receive a proportion of the total sales revenue. The growing predominance of huge international petroleum combines in world sulfur is particularly evident in western Canada. In this way owners of sulfur production are by and large subsidiaries controlled by parent groups overseas. For example: Shell Canada Ltd. by Anglo Dutch Shell, Aquitaine Co. of Canada by French Aquitaine Group (S.N.P.A.), Chevron Standard Ltd. by Standard Oil of California.

2.2 Origins of Hydrogen Sulfide

The understanding of the origin of sulfur compounds in crude oil and natural gas is still at an unsatisfactory stage. It seems doubtful that sufficient organic sulfur was present at the time of deposition to account, in all cases, for the quantities of combined sulfur found associated with oil and natural gas. Conjecture suggests anaerobic bacteria could have oxidized hydrocarbons to carbon dioxide (CO_2) using the oxygen in the sulfates sometimes associated with source and reservoir rocks, and in so doing produce hydrogen sulfide. Other studies (Hitchon & Krouse) employing sulfur isotope analyses suggest a combination of physical conditions such as temperature and pressure and lack of oxygen are responsible for the conversion of sulfate to hydrogen sulfide. The amount of hydrogen sulfide found in a given gas field or pool cannot be determined beforehand; it is a function of the environment during deposition, the origin of the particular sediments and their geologic history to the present. Generally speaking the deeper the field the higher the hydrogen sulfide content of the natural gas. It is usually the case that all wells drilled in a given field produce gas of similar composition. However, exceptions can be shown where, for example, the hydrogen sulfide content varies considerably from one end of a field to the other end. In this case the field may contain more than one independent pool or reservoir, from which feed stock is blended to make up the raw gas inlet the plant has been designed for.

2.3 Sour Gas Processing

A given processing facility normally treats gas from only one field, although it is by no means unusual that plant inlet gas be blended from more than one field. The raw gas composition upon which the processing unit operates varies from field to field. Thus one establishment may be confronted with a gas containing 15% carbon dioxide and 0.5% hydrogen sulfide, whereas another must be designed to operate on a sour gas of 55% hydrogen sulfide and 1-2% carbon dioxide. The relative amounts of hydrogen sulfide and carbon dioxide, water vapour and hydrocarbons have a pronounced effect on the design and operation of the plant. All those units indicated schematically in Figure 3.1 exist as a group of physical entities on one site and thus constitute the sour gas processing plant.

Gas processing includes a variety of treatments each designed to suit the gas to be processed. The simplest installations are separators, usually at or near the well, to separate the liquid hydrocarbons and water that condense from the reservoir gas in the well or at the well head. Such installations are not considered gas processing plants today although they were employed as such in the early days of the Turner Valley field; instead they are considered as equipment used in field production.

From the field site to the processing plant the raw gas must be kept near or above 80°F to prevent the formation of pipe-line-plugging, solid compounds between the water and hydrocarbon natural gas. For this purpose in-line heaters are placed at stategic points along the gas line leading into the plant. Water and hydrogen sulfide represents a potentially dangerous corrosive mixture, therefore corrosion inhibitors are also continuously metered into the raw gas stream on its way to the plant. Such compounds presumably adhere as a protective coating to the interior of the pipeline, thus preventing hydrogen sulfide from attacking the pipe wall. These operations are also not normally considered part of gas processing since this gas still needs further treatment in plants capable of producing products to meet standard specifications. It is these more complex installations and equipment that are classified as gas processing plants.

For the sake of completeness and to direct attention to less obvious sources of possible environmental contamination, the origin of which may be placed with sour gas plants, a somewhat detailed analysis of the various unit operations in gas processing follows in Part 3. Such information will also lead to an appreciation of the complex variables plant management faces and can no doubt expect in greater degree as our concern with the quality of the environment deepens.

2.4 Summary of Unit Operations

In some cases, where the hydrogen sulfide content is low, the separated hydrogen sulfide is incinerated. In others, where hydrogen sulfide constitutes a relatively large proportion of the gas, it is recovered and processed to elemental sulfur. In brief, the hydrogen sulfide contained in sour natural gas is absorbed at a sulfur recovery plant located at or near the gas producing field. This absorbed acid gas fraction containing hydrogen sulfide is regenerated and partially burned under controlled conditions. During this combustion process elemental sulfur is released from a vapour containing unreacted hydrogen sulfide. This vapour containing hydrogen sulfide and sulfur dioxide is subsequently passed over a sequence of catalytic converters and condensers where liquid sulfur is formed, collected, and run to storage vats. Any hydrogen sulfide unreacted is then combusted to sulfur dioxide and released through a stack to the atmosphere.

2.5 Constituents Extracted from Natural Gas

The main constituents extracted from natural gas include hydrogen sulfide, which must be removed because it is both corrosive and toxic, carbon dioxide, which lowers the heat value of the gas, and a group of liquid hydrocarbons, so called because of the relative ease with which they may be liquified from a raw gas stream.

The lightest liquid hydrocarbon is propane. The next heaviest of the liquid hydrocarbons are the butanes. These are followed by a group called pentanes plus which contains not only pentanes but varying quantitites of heavier constituents such as hexanes, heptanes, octanes, etc.

Condensate refers to liquid hydrocarbons that condense at the well head, usually in simple separators. Condensate may contain varying amounts of the liquid hydrocarbons referred to in the previous paragraph as well as crude oil.

PART 3

DETAILED PLANT OPERATIONS

3.1 Plant Diagram and Gas Analysis

Figure 3.1 is a simplified flow diagram of the processes which take place in a typical gas processing plant. Table 3.1 presents sample analyses of some of the important gas streams entering, within, and leaving the processing plant. The numbers at the column headings refer to the points of analysis shown in Figure 3.1. It is to be noted that Table 3.1 analyses are on a dry basis, i.e. they overlook the water vapour that is present at concentrations which also depend upon the point of analysis. Furthermore, the calculated compositions are in terms of mole per cent and must therefore be multiplied by 10,000 to convert them to parts per million (ppm) by volume, again on a dry basis. The individual operations designated in Figure 3.1 will now be discussed in some detail.

3.2 Inlet Separation

The inlet separation facilities normally consist of a vertical or horizontal separator into which flow the raw gas, condensate and produced salt water from the field gathering system. Sufficient retention time is provided to allow gravity separation of the three "phases" entering the separator. The gaseous phase is drawn off the top of the separator and flows to the gas sweetening facilites if sour, or directly to the dew-point control facilities if sweet. The hydrocarbon liquid phase (condensate) is drawn off from a mid-point in the separator and directed to the condensate stabilization facilities. The produced salt water is drawn off the bottom of the separator. The water may then be treated in a sour water stripper, if it contains hydrogen sulfide, before being injected through a disposal well to an underground formation. Stripping of the hydrogen sulfide from the water is accomplished using sweet gas or steam in a small column. The hydrogen sulfide stripped from the water should not be vented to the atmosphere, as it represents a potential source of pollution, but is generally directed either

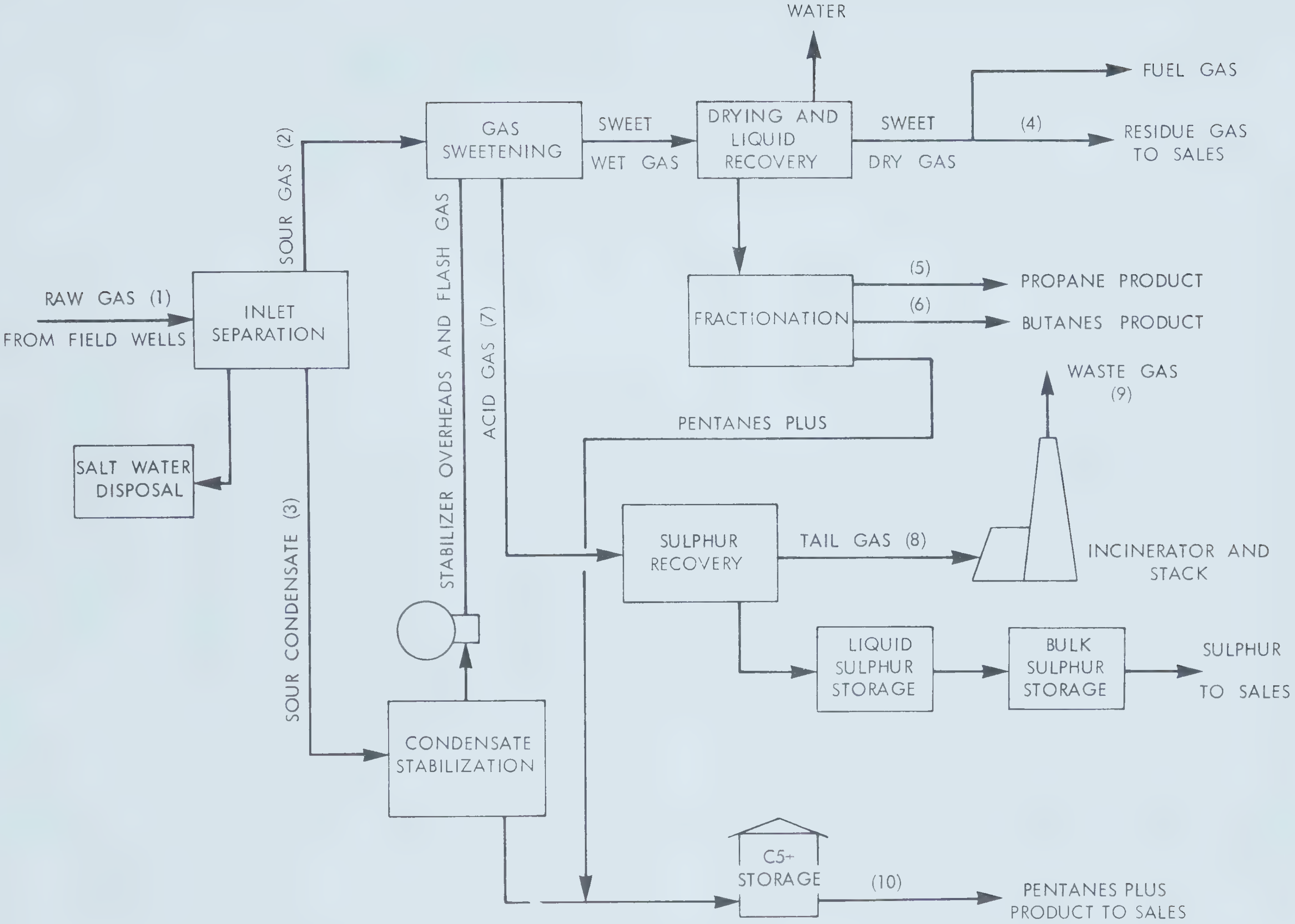

FIGURE 3.1 - SIMPLIFIED FLOW DIAGRAM OF A GAS PROCESSING PLANT. (Reference 1)

TABLE 3.1
EXAMPLE GAS COMPOSITIONS*
(MOLE %)

Compenent	Symbol	1 Raw Gas	2 Sour Gas	3 Sour Con-densate	4 Sales Gas	5 Propane Product	6 Butanes Product	7 Acid Gas	8 Tail Gas	9 Stack Gas	10 Pentanes Plus
Nitrogen	N_2	0.94	1.08	Tr	1.33	----	----	----	85.52	87.47	----
Methane	C_1	65.66	73.78	11.90	92.93	----	----	1.37	----	----	----
Ethane	C_2	3.59	3.40	4.62	5.16	2.99	----	0.19	----	----	----
Propane	C_3	1.25	0.84	3.71	0.58	96.09	1.05	0.10	----	----	0.05
Isobutane	iC_4	0.29	0.14	0.45	----	0.90	32.14	0.06	----	----	0.39
Normal Butane	nC_4	0.74	0.28	3.91	----	----	65.76	0.09	----	----	3.29
Pentanes	C_5	0.79	0.10	5.66	----	----	1.05	----	----	----	13.31
Hexanes	C_6	0.90	Tr	7.20	----	----	----	----	----	----	15.61
Heptanes Plus	C_7+	3.88	----	32.96	----	----	----	----	----	----	67.32
Hydrogen Sulphide	H_2S	17.66	15.93	27.55	----	----	----	76.94	1.84	----	0.04
Carbon Dioxide	CO_2	4.30	4.45	2.04	----	----	----	17.89	10.86	7.30	----
Sulphur Dioxide	SO_2	----	----	----	----	----	----	----	0.75	1.73	----
Carbon Disulphide	CS_2	----	----	----	----	----	----	----	0.41	----	----
Carbonyl Sulphide	COS	----	----	----	----	----	----	----	0.62	----	----
Sulphur Vapour	Sv	----	----	----	----	----	----	----	Tr	----	----
Sulphur Liquid	S_1	----	----	----	----	----	----	----	Tr	----	----
Oxygen	O_2	----	----	----	----	----	----	----	----	3.50	----
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

*Analyses are example analyses only and do not represent a material balance about the plant.

back to the plant for further processing, to a flare or to the sulfur plant incinerator.

3.3 Gas Sweetening Facilities

Reversible selective absorption in an aqueous solution of an amine is the most common method used in Alberta to remove acid gas (hydrogen sulfide and carbon dioxide) from raw gas streams. Transfer of the acid gas from the raw gas takes place as cool, lean (pure) amine solution flowing countercurrently downward in a scrubbing tower is contacted with the gas. The acid gas absorption into the solvent is directly proportional to the pressure, consequently the pressure in these contactors ranges from 400-900 pounds per square inch gauge (psig), depending upon the desired hydrogen sulfide content of the resultant sweetened gas leaving the top of the tower. The hydrogen sulfide and carbon dioxide are stripped from the rich amine (hydrogen sulfide, carbon dioxide saturated) when it is heated under decreased pressure (5-10 psig) in a solvent regenerator. The regenerated amine solution is then ready for another cycle after being cooled.

The treating solutions most commonly used are mono-ethanolamine (MEA), di-ethanolamine (DEA) and Sulfinol, a mixture of di-isopropanolamine (DIPA) and sulfolane. The choice of solutions depends to some extent upon the ratio of hydrogen sulfide to carbon dioxide in the raw gas and also upon a variety of other considerations which need not be discussed here. Although the typical gas analysis (Table 3.1) did not so indicate, some sour gases contain carbonyl sulfide (COS) and carbon disulfide (CS_2) as part of their total sulfur value. MEA and DEA will generally remove these compounds without degradation of the solvent, but will not easily regenerate them. Hence they will accumulate through the cycle. Sulfinol, used in the case of very high acid gas content, also is quoted as removing carbonyl sulfide and carbon dioxide without degradation of the solvent. Its disadvantage is its affinity for heavy hydrocarbons (C_4+) and aromatics which would carry over with the hydrogen sulfide and carbon dioxide to the Claus unit (described below) and result in a poor quality of sulfur.

All these chemicals are circulated in a water solution. In an MEA treating plant the treating solution is normally from 15% to 20% MEA and from 85% to 80% water. In a DEA treating plant the treating solution is normally from 25% to 30% DEA with the remainder water. In a Sulfinol plant the treating solution is normally 45% DIPA, 35% sulfolane and 20% water.

The wet acid gases, regenerated as described above, are cooled, condensed water (H_2O) is separated in a reflux accumulator and the acid gas is directed to the sulfur plant at 5-10 psig.

A diatomaceous earth filter system is normally required to remove corrosion products and other intractable compounds from the amine solution. In addition a rich amine solution flash tank is sometimes installed to remove absorbed hydrocarbons from the rich MEA or DEA solution prior to regeneration of the acid gases.

Other sweetening processes are available and are described in the references listed for this section.

3.4 Sulfur Recovery

The acid gas (hydrogen sulfide and carbon dioxide) from the gas sweetening plant is directed to the sulfur recovery plant where elemental sulfur is recovered from the hydrogen sulfide contained in the gas using the Claus process, named after its inventor. There have been modifications to the Claus process from time to time and from plant to plant, but the process is basically as outlined below.

The acid gas enters a free flame combustion furnance at 1700-2200^{o}F where the hydrogen sulfide is burned in a deficiency of oxygen (air). This step is necessary in order to produce sufficient sulfur dioxide for a subsequent more efficient catalytic reaction between sulfur dioxide and unreacted hydrogen sulfide, which yields additional elemental sulfur. The ratio of air to hydrogen sulfide and the residence time of the gases in the furnace must be very carefully regulated so that the following reactions occur in the proper proportions:

$$2H_2S + 3O_2 \rightleftharpoons 2SO_2 + 2H_2O \qquad (3.1)$$

$$2H_2S + O_2 \rightleftharpoons 2S + 2H_2O \qquad (3.2)$$

$$2H_2S + SO_2 \rightleftharpoons 3S + 2H_2O \qquad (3.3)$$

Reactions (3.2) and (3.3) imply sulfur is also formed in this partial combustion process, and indeed approximately 50% of the conversion of hydrogen sulfide to sulfur is accounted for in this way. In practice the chemistry is not quite as simple or completely understood as indicated by equations (3.1) to (3.3) because the gas leaving the front end furnace contains hydrogen (H_2), carbonyl sulfide, carbon disulfide, and by inference sulfur trioxide (SO_3) as well as the products indicated in the above equations.

The hot gas stream leaving the reactions furnace is then cooled in the first sulfur condenser to condense most of the sulfur vapour formed in the furnace. In order to promote a further reaction between sulfur dioxide and hydrogen sulfide to form more sulfur, the gas stream leaving the first condenser enters the first catalytic converter after being preheated with either hot gas from the reaction furnace or an in-line burner. The catalysts normally employed in the converters to catalyze sulfur production are naturally occuring bauxite, or activated alumina. The choice of catalyst and duration over which it maintains its activity, or efficiency, varies depending on the gas composition entering the Claus unit.

The sulfur vapour formed in the catalytic converter is subsequently condensed in the second condenser and removed from the gas stream. This process is repeated for up to a total of four stages of catalytic conversion. Typical recovery percentages have been calculated for various acid gas feed concentrations of hydrogen sulfide from 20-90% for two, three and four reactors, Table 3.2 and Figure 3.2

TABLE 3.2

TYPICAL CLAUS PLANT SULFUR RECOVERY FOR VARIOUS FEED COMPOSITIONS WITH NORMAL ORGANIC CARRY-OVER AND ENTRAINMENT ALLOWANCE
(Reference 3)

Hydrogen sulfide in sulfur plant feed (dry basis) %	Two Reactors	Three Reactors	Four Reactors
20	92.7	93.8	95.0
30	93.1	94.4	95.7
40	93.5	94.8	96.1
50	93.9	95.3	96.5
60	94.4	95.7	96.7
70	94.7	96.1	96.8
80	95.0	96.4	97.0
90	95.3	96.6	97.1

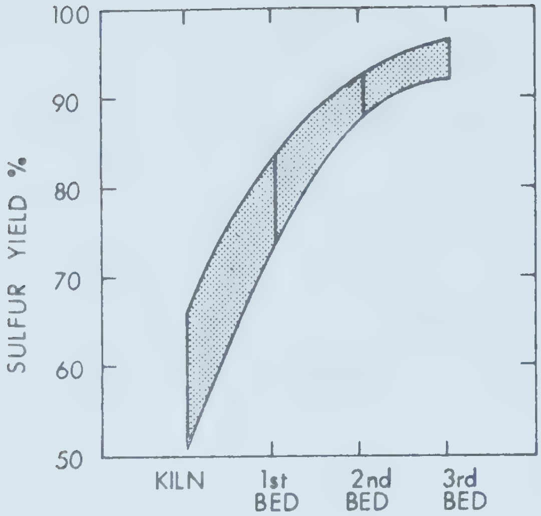

FIGURE 3.2 - PERCENT SULFUR RECOVERED IN CLAUS PLANTS AS A FUNCTION OF THE NUMBER OF CLAUS CONVERTERS, ASSUMING 1 MOLE PERCENT HYDROCARBON CONTAMINATION AND CATALYST TEMPERATURES OF 400-500°F. (Reference 4).

These calculations assume one mole percent hydrocarbon contamination and conventional catalyst temperatures of 400-500°F.

It must be appreciated that chemical reaction(3.3) is a reversible reaction, i.e. it can occur in both directions. As a result, complete conversion to sulfur and water can never occur since sufficient water and sulfur vapor are always present to limit conversion. Additionally, carbon dioxide, water vapor and nitrogen in the feed stock shift the Claus equilibrium adversely. Hydrocarbons and carbon dioxide cause great difficulty by increasing undesirable side reactions,forming carbonyl sulfide and carbon disulfide which are difficult to convert to elemental sulfur. As little as five gallons of hydrocarbon and/or amine carried over to the Claus unit per million standard cubic feet of gas processed (in the order of 80 parts per million) can also cause production of dark, impure, off-coloured sulfur. Some plants have had success in using a cobalt-molybdenum catalyst in the first converter to transmute carbonyl sulfide and carbon disulfide to sulfur.

The reaction between sulfur dioxide and hydrogen sulfide to form sulfur (reaction (3.3)) is exothermic (librates heat), hence lower temperatures favor the formation of sulfur in the catalyst converters. The lower practical limit here is that temperature which maintains the sulfur as a vapor (400-500^{0}F).

The lower practical temperature for the sulfur condensing steps is set at 260^{0}F by the solidification of the sulfur product and plugging of the apparatus. A further temperature limitation is established at the point where water condenses. Hydrogen sulfide and sulfur dioxide in the presence of liquid water react to form complex polythionic acids ($H_2 S_x O_3$) known as Wackenroder's solution. This solution is extremely corrosive to all known construction metals with the possible exception of titantium.

3.4.1 Operating Limitations

In summary then, a sulfur recovery unit as presently designed never matches its theoretical performance due to the following factors:

(1) Decline in catalyst activity;

(2) Side reactions involving loss of sulfur;

(3) Entrained sulfur mist in condenser outlets;

(4) Exact air and gas ratio control is never continuously achieved, even with the most sophisticated instrumentation;

(5) Results on carefully operated plants indicated 0.5-1 percent below theoretical recovery rate after initial start up and this will decline about 0.5 percent more before the catalyst is replaced because of deactivation. These conclusions are included in Figure 3.2, but not in Table 3.2.

3.5 Incineration

Finally, the gas leaving the last condenser flows through a coalescer which removes fine droplets of liquid sulfur entrained in the gas stream. The gas stream then flows to the incinerator. In the incinerator sufficient fuel gas and air are added to completely oxidize any unrecovered sulfur in the form of hydrogen sulfide, entrained sulfur liquid, sulfur vapor, carbonyl sulfide and carbon disulfide (these latter two may be formed in the reaction furnace due to the presence of carbon dioxide and trace amounts hydrocarbons in the acid gas stream) to sulfur dioxide. The gas stream leaving the incinerator then flows to the stack for dispersal to the atmosphere. The stack is designed to discharge the sulfur dioxide to the atmosphere at a sufficiently high velocity, to a sufficient height and at a sufficiently high temperature (normally 1000°F) so that the sulfur dioxide will disperse to a concentration which will not result in a hazard to vegetation, human or animal life, when it settles to the ground.

It should be noted from Table 3.1 that the stack gases normally contain from one to two percent sulfur dioxide. The remainder is primarily nitrogen, from the air added to the sulfur plant reaction furnace and to the incinerator, carbon dioxide from the acid gas and carbon dioxide formed due to the burning of fuel gas in the incinerator. There also should be excess oxygen present to ensure that all combustible sulfur compounds are fully oxidized to sulfur dioxide. Considerable water vapour, which is a product of the various combustion reactions which take place in the sulfur plant and in the incinerator, is also present in the stack gas.

3.6 Elemental Sulfur

The recoverable sulfur product flows into a heated underground pit and after gauging is either pumped to tank cars, or is cast into large blocks and stored in the open. Considerable experimental work is being done with pelletized and slated forms of solid sulfur to avoid the sulfur dust problem associated with cast solid sulfur. An Alberta company is presently the world leader in equipment designed for slating and handling of slated sulfur.

3.7 Heat Generation

Large amounts of heat are generated by the various exothermic reactions which take place in the sulfur plant reaction furnace and catalytic converters. A part of this heat is recovered in the reaction furnace waste heat boiler and in the sulfur condensers where it is used to either preheat boiler feedwater or generate steam. This steam is normally used throughout the rest of the plant for process heat requirements and to drive process pumps, compressors, etc. For this reason many of the plants processing highly sour gas with considerable steam generation are dependent on the operation of the sulfur plant for steam required in the remainder of the plant.

3.8 Determination of the Efficiency of Sulfur Recovery Plants

Some of the methods presently applied to determine plant input and sulfur recovery are not compatible with present trends in air quality requirements. In order to establish sulfur recovery efficiency, it is assumed that one must be able to determine a minimum of two of the following three parameters: (1) sulfur input; (2) sulfur production; (3) sulfur emissions.

Sulfur input is deduced from measurements of acid gas flow rates from the field as found from orifice flow meters (accurate to ± 2%). In the case of large plants this could entail the reading of up to twenty flow meters. The wet chemical Tutwiler method of sulfur analysis is potentially accurate to ± 1%. The more refined gas-chromatographic method of sulfur analysis, as of this date, has been employed by the newer and larger plants, some only on a spot check basis. It is fast, accurate to ± 1% and capable of integration with computerized monitoring of plant operation.

Sulfur produced from a Claus plant is held as a liquid in a heated pit where daily production is checked with a floating pit gauge. The measurement of sulfur produced as found from pit gauge is perhaps the area where least accuracy will be encountered.

In the past the Department of the Environment (previously the Department of Health) made standard incinerator stack surveys involving measurement of gas flow velocity profiles followed by wet chemical analysis for sulfur dioxide.

This was a tedious and unappealing manual operation carried out at upwards to 150 feet up the stack. It is obvious why it wasn't done on a routine basis. With the advent of gas chromatographic techniques, and infrared and ultraviolet analysis procedures, it has been feasible to operate continuous stack surveys of sulfur dioxide, and in some cases to ascertain whether other sulfur compounds also contribute to lost sulfur values. Since the amount of sulfur unconverted and incinerated is a small percentage of the sulfur fed to the Claus plant, errors as large as ± 5% in such measurements would contribute little error to the calculated sulfur plant efficiency.

It is therefore feasible, and in fact is practiced at the large plants, that sulfur recovery efficiency be based upon assessment of sulfur input (determined as the sum of sulfur produced, sulfur emitted as sulfur dioxide, and sulfur contained in the condensate and pentanes plus fractions) and sulfur lost (sulfur emitted through the stack and sulfur in the condensate). This should afford an accuracy of about one percent in evaluating the sulfur recovery efficiency using an expression of the form

$$\text{Percent Sulfur Recovered} = 100\left(1 - \frac{\text{Sulfur lost}}{\text{Sulfur input}}\right) \qquad (3.4)$$

Some plants have found it useful to evaluate the amount of hydrogen sulfide, sulfur dioxide, carbonyl sulfide and carbon disulfide in the tail gas prior to incineration. While this is useful information which may be used to regulate plant operation, as a method of defining sulfur productivity it overlooks possible entrained sulfur vapor which would be converted to sulfur dioxide in the incinerator.

3.9 Sweet Gas Treatment

To re-affirm the two-product nature of the sour gas treatment facility and to draw attention to the difficulty in dealing solely with a sulfur producing operation in any discussion of the environmental effects of the latter, we must consider here the procedures needed to prepare the sweet gas for market. They occur at the same location as do those of sulfur recovery and involve chemicals and waste material disposal which cannot be overlooked.

3.9.1 Drying and Liquid Recovery

Sweet gas leaving the gas sweetening facilities is water saturated and may contain appreciable quantities of recoverable propane, butanes and some pentanes plus. The water contained in the gas must be removed before the gas is sold and the operator may also wish to install facilities to recover the LPG's (liquified petroleum gases) and pentanes plus.

Even if no liquid hydrocarbon recovery is planned facilities are provided for drying the gas. These facilities normally consist of either desiccant drying towers or glycol contacting facilities.

3.9.1.1 Dry Desiccant Drying

A desiccant drying system normally consists of two or more parallel columns containing desiccant pellets (silica-gel or some other silicon-oxide based material) through which the gas is passed. Water contained in the gas is adsorbed by the porous desiccant material. The drying towers are normally operated on a timed cycle. One tower may be used for adsorption while a second is being regenerated (with hot dry gas) and a third is being cooled following regeneration. The gas flows are switched from tower to tower at the end of each timed cycle by automatically controlled switching valves. Water is removed from the regeneration gas stream by cooling the regeneration gas to below its water dew point.

3.9.1.2 Glycol Drying System

In a glycol drying system the wet gas stream flows upward through a trayed column and is contacted by a countercurrent flow of lean glycol (normally tri-ethylene glycol). The glycol absorbs the water contained in the gas. The glycol leaving the contactor is regenerated with heat and pumped back to the contactor. Water removed from the glycol during regeneration is normally vented to the atmosphere as a vapour.

If liquid hydrocarbons are to be recovered from the gas stream the water removal and liquid hydrocarbon removal processes normally take place simultaneously. In some plants desiccant towers are used for the removal of both water and liquifiable hydrocarbons. In most plants however, either a refrigeration or a refrigerated absorption process is used.

3.9.1.3 Refrigeration Process

In a refrigeration plant the gas stream is cooled through heat exchange with a refrigerant (normally boiling propane) to liquefy the water and heavier hydrocarbons. Ethylene glycol is injected into the gas prior to refrigeration to prevent the formation of hydrates during the cooling. The water-glycol and liquid hydrocarbon phases are then removed separately from the dry residue gas stream in a low temperature separator. The recovered liquid hydrocarbons then either flow to the fractionation facilities for separate recovery of propane, butanes and pentanes plus or following a stabilization procedure, flow to the pentanes plus storage tanks if they contain only small amounts of propane and butanes. The amount of pentanes plus produced in this manner is normally small compared to the amount produced from the condensate stabilization facilities. In certain cases the LPG - pentanes plus mix is not fractionated but is sold as a mixed LPG product. This is the situation at the new Imperial Oil Quirk Creek Plant.

3.9.1.4 Refrigerated Absorption Process

If "deep-cut" LPG recovery is required the gas from the low temperature separator flows through a low temperature absorber where it is contacted countercurrently with a refrigerated low molecular weight absorption oil. The oil absorbs any liquefiable gases remaining in the dry residue gas stream. The gas stream leaving the absorber then goes to sales. The rich oil is regenerated first in a rich oil de-ethanizer (absorbed ethane and methane are removed) and then in a rich oil still where the absorbed LPG's are removed and directed to the fractionation facilities. The regenerated lean oil is then refrigerated and returned to the absorber.

The glycol injected into the wet gas stream prior to refrigeration is recovered in the low temperature separator with the water and is regenerated in the glycol regeneration facilities.

3.9.2 Fractionation

Mixed liquiefiable hydrocarbon gases from the refrigeration plant are directed to the fractionation plant for separation to propane, butane and pentanes plus. This separation is accomplished in a series of fractionation columns, each containing several trays. The feed to each column enters at approximately the mid-point. The operating pressure and temperatures of the columns are such that the lightest hydrocarbon in the feed is removed from the top of each column as a vapour and the heavier hydrocarbons are removed from the bottom in the liquid phase. Heat is added to each column at the bottom using a reboiler and heat is extracted at the top using an overhead condenser. In this manner the bottom temperature is held higher than the top temperature.

3.9.3 Condensate Stabilization

Raw condensate from the inlet separator flows to the condensate stabilization facilities. From the analysis of stream 3 in Table 3.1, it can be seen that this condensate can contain a considerable amount of light hydrocarbons and acid gases. The condensate stabilization facilities are provided to remove these light hydrocarbons and acid gases from the condensate in the production of a stabilized pentanes plus product. The presence of large quantities of the gases in the pentanes plus product would result in a considerable loss of sour hydrocarbon vapours to the atmosphere from the pentanes plus storage tanks and a resultant pollution and personnel safety problem.

The condensate from the inlet separator therefore is stabilized by first "flashing" it at a low pressure in a condensate flash tank and then by heating it and feeding it to a low pressure condensate stabilizer column. This column fractionates the lighter components and much of the hydrogen sulfide and carbon dioxide from the final pentanes plus product. The vapours removed from the condensate are normally compressed and sweetened in the gas treating plant.

The pentanes plus product is normally stored in atmospheric pressure storage tanks before delivery through a pipeline to a refinery for further processing.

3.9.4 Small Gas Processing Plants

In many cases processing plants do not recover all the products mentioned above. In these cases the process employed is greatly simplified.

3.9.5 Pipeline Extraction Plants

Four pipeline straddle plants operate in the Province (two near Empress, one near Cochrane and one in Edmonton). These plants process pipeline natural gas for the recovery of LPG's. All four plants use a refrigerated oil absorption process to recover these LPG's.

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PART 4

REGULATORY AGENCIES GOVERNING THE OPERATIONS ASSOCIATED WITH PROCESSING PLANTS

4.1 General

A broad collection of regulations and guidelines already circumscribe allowable practices appropriate for the gas processing industry. The current concern with environmental issues keeps these guidelines constantly under governmental review. In spite of this fact occasional public forums such as that anticipated in the present instance do provide an often necessary degree of intensity to such reviews.

Thus, while it may be of value to catalogue here the existing regulations pertinent to sour gas processing, we are also aware that these standards are constantly under review and up-dated in keeping with technological advances in the industry. Not only are the industry's codes being revised but also the monitoring and enforcement capabilities of the responsible private and governmental agencies have been improved in quantity and sophistication. The increasing number of deleterious compounds for which the Department of the Environment exercises state-of-the-art detection facilities should also assist in assuring the public that their concern has been noted and that scientists are acting upon their inherent concern for the welfare of the province.

4.2 Statutory Responsibility for Regulation of the Gas Industry

In 1970, through amendments to the Oil and Gas Conservation Act, the Oil and Gas Conservation Board was assigned responsibility to control pollution in oil and gas field operations. During 1971 the legislature of Alberta, by passing the Energy Resources Conservation Act and the Hydro and Electric Energy Act, consolidated Energy Resource Management within the Energy Resources Conservation Board. Furthermore, it charged the Board to broadly manage energy matters in balance with other environmental matters. Also during the 1971 session of the legislature, the Department of The Environment Act was passed and this was complemented with the Clean Air Act and the Clean Water Act. The Department of The Environment Act not only established the Department but also granted the Minister responsibilities and duties in connection with environmental matters.

Environmental matters were defined as those legal or economic factors and any operations or activities which directly or indirectly affect the quality or quantity of any natural resource in the various phases of resource utilization, with specific emphasis on the prevention of degradation or pollution of those resources.

Specifically, the Minister was charged with the co-ordination of policies, programs, services, and administrative procedures of all government Departments and agencies, in matters pertaining to the environment. The Clean Air and Clean Water Acts both give the Minister the responsibility of setting maximum permissible levels of pollutants and the approval of all plans and specifications to ensure that these standards are not exceeded, as well as the setting of emission control standards and the halting of any operation or activity exceeding these standards.

The 1972 legislative amendments to several statures, including the Oil and Gas Conservation Act and recently agreed upon administrative procedures, confirmed the Board's general role as defined earlier in 1970 but made it clear that regulations and conditions of approvals affecting environmental matters are now subject to the approval of the Department of The Environment. The present situation, therefore, is that overall responsibility for pollution control is consolidated within the Department of The Environment.

In oil and gas operations, the Energy Resources Conservation Board, in effect, is delegated responsibility for devising and administering the ways and means required to ensure that the standards are met. This means devising conditions of approval, devising the regulations subject to the Department of the Environment's approval and taking corrective action where required. It also means that the Board will continue to be the principal communication link with the industry on pollution control matters.

Table 4.1 outlines current division of responsibilities for those matters of direct concern to the Board, the Departments of Environment, Lands and Forests, Mines and Minerals, and Agriculture. The Department of The Environment sets province wide air quality, water quality, surface and groundwater use, and watershed protection standards criteria. The Boards role with respect to control of pollution of surface and groundwater is to enforce its prohibition of the disposal of hydrocarbons, produced water or other field wastes to any body of surface water, and to enforce regulations to protect domestic sources of groundwater from pollution or depletion by the oil and gas industry. Proper housekeeping at well and battery sites during drilling operations and producing operations is the responsibility of the Board. Final reclamation of abandoned sites in the unsurveyed areas is administered by the Department of Lands and Forests as provided in the surface lease. Abandonment and reclamation of sites on other lands are administered by the Department of the Environment. The sale of oil and gas leases is administered by the Department of Mines and Minerals. The Boards pipeline division oversees the approval and testing of pipelines and the cleanup of oil spills resulting from pipeline breaks. The Department of The Environment and Lands and Forests approve the location of pipelines and advise on specifications for river crossings.

The co-ordination of these activities is the responsibility of the Department of The Environment. The Minister of the Department of The Environment may issue stop orders where necessary to protect the environment.

TABLE 4.1

OIL AND GAS INDUSTRY ENVIRONMENT CONTROL RESPONSIBILITY

(Reference 1)

ENVIRONMENT ELEMENT	ENERGY RESOURCES CONSERVATION BOARD RESPONSIBILITY	DEPT. OF THE ENVIRONMENT RESPONSIBILITY	DEPT. OF LANDS & FORESTS RESPONSIBILITY	DEPT. OF MINES & MINERALS RESPONSIBILITY
1. Air	1. enforce air quality standards in oil and gas industry.	1. set air quality standards for the province. 2. enforce air quality standards (except oil and gas, coal and electric power industries).		
2. Surface Water	1. prohibit disposal of hydrocarbons, produced water, and other oil-field wastes to surface water. 2. request government forces to clean up catastrophic oil spills.	1. control use of surface water. 2. set, monitor and enforce water quality standards. 3. set, monitor and enforce effluent waste quality.	1. enforce Federal fish and game bird acts pertaining to water pollution. 2. co-ordinate and assist fire fighting force to clean up catastrophic oil spills.	

(cont'd)

ENVIRONMENT ELEMENT	ENERGY RESOURCES CONSERVATION BOARD RESPONSIBILITY	DEPT. OF THE ENVIRONMENT RESPONSIBILITY	DEPT. OF LANDS & FORESTS RESPONSIBILITY	DEPT. OF MINES & MINERALS RESPONSIBILITY
3. Subsurface Water	1. protect domestic groundwater from pollution or depletion by oil and gas industry.	1. administer use of groundwater for non-domestic purposes.		
4. Land	1. control disposition of oil and gas industry waste material to surface. 2. enforce good housekeeping in oil and gas industry operations. 3. supervise clean-up of non-catastrophic oil spills.	1. enforce reclamation of land surface affected by industry operations.	1. issue surface lease. 2. enforce reclamation of land surface affected by industry operations on unsurveyed lands. 3. co-ordinate clean up of catastrophic oil spills.	1. mineral sales.

The Energy Resources Conservation Board has five field offices throughout the province to carry out field inspections. Total field office staff at June 30, 1972 is 71, with 32 in Edmonton, 17 in Red Deer, 8 in Drayton Valley, 7 in Black Diamond and 7 in Medicine Hat. This field staff is made up of 5 engineers, 45 technicians, 8 pipeline inspectors, 5 summer employees (students) and 8 typists, stenos and clerks. There are one or two gas processing plant specialists in each field office but other field office personnel may carry out gas plant inspection work when required. In addition to the field staff, three Calgary based people are working on gas plant stack surveys during the summer and approximately eight additional Calgary based personnel may become directly involved in gas plant inspections and pollution investigations in special circumstances. Funds for that portion of the Board's responsibilities which apply to the oil and gas industry are provided by the provincial government and the oil and gas industry on an equal share basis.

The Board maintains a close liaison with the Canadian Petroleum Association, the Independent Petroleum Association of Canada and the Canadian Association of Oil Well Drilling Contractors. Committees from these agencies work with the Board in arriving at reasonable regulations. Public participation takes place only at hearings in consideration of individual gas processing applications.

Regulations are enforced through monthly surveillance of company reports, field inspections and in answer to specific complaints brought to its attention. All Board regulations are subject to change and hence are a function of time. Stricter regulations and control procedures have already been announced to the industry for the immediate future. Therefore, complaints made against the industry must be considered in terms of the constraints applied to the industry at the time of the complaint. It would appear that reported incidents of infractions, at one time quiescent, went through a peak and now are again relatively few, due in measure to tighter strictures upon the industry, arising out of these earlier incidents.

The day-to-day involvement of the Board and the Department of the Environment with the industry is through the issuance of regular 'Information Letters' on the part of the Energy Resources Conservation Board and "Air Monitoring Directives" by the Department of the Environment Pollution Control Division, examples of which are cited in the references for this section.

In addition, there is the basic legislation embodied in the Clean Air Act, the Ambient Air Quality Standards of Alberta and the provisions of the Oil and Gas Conservation Regulations which the Board is bound to enforce. The Ambient Air Quality standards are attached to this report as Appendix I.

4.3 Regulations by Contaminant

The following specific operating standards are enforced by the Board to ensure achievement of the objectives as embodied in the above legislation:

Oil - Disposal of waste oil is permitted only in limited amounts and it must be contained. Pit storage is prohibited and flaring must be smokeless.

Gas - Disposal as a waste is permitted in limited amounts where no practical means of conserving the gas exists. Disposal must be through smokeless incineration.

Sour Gas - No venting of hydrogen sulfide without conversion to sulfur dioxide. Venting of sulfur dioxide must be such that calculated ground level concentrations averaged over a one-half hour period, are maintained at or below 0.2 part per million in populated or agricultural areas or 0.3 part per million in all other areas.

Gas Processing Odors - Limited so that no odor complaints arise from nearby residents.

Drilling Mud - Appropriate on-lease disposal is permitted but no off-lease disposal except to approved locations.

Salt Water - No surface disposal is permitted except to approved storage pits in amounts of less than 100 barrels per month per pit. All other disposal must be to underground formations in accordance with schemes approved by the Board.

Smoke - Essentially no visible smoke is permitted from the burning of hydrocarbons.

4.4 Regulation by Operation

4.4.1 The Battery

A battery (a gathering point for treating collectively the fluids from a number of wells) processing oil, salt water and sour gas presents hazards from all the major pollutants present in the industry. The regulations are designed to minimize spills and leaks from processing equipment. Disposal of waste products is controlled to prevent pollution of soil, air or water.

Approval of the location and design of a battery must be obtained prior to construction if the gas contains more than one per cent hydrogen sulfide.

1. The operator is required to gather solution gas where it is economically feasible to do so. Where sour gas production results in a potentially serious pollution problem, gathering may be

required even though it cannot be justified on economic grounds.

2. Relief valves from pressure vessels must be piped to a tank to prevent oil from spraying over the lease.
3. Sour tank vapours from oil or salt water tanks must be collected and flared through an elevated stack.
4. Dikes must be constructed around storage tanks. If the battery is close to lakes or streams another dike surrounding the battery is required.
5. Where sour solution gas is not gathered, it must be flared through a stack of sufficient height to ensure that half hour maximum ground level concentrations of sulfur dioxide are below 0.2 part per million.
6. Storage of salt water in earthen pits is limited to 100 barrels per month. Subsurface disposal of salt water is encouraged.

4.4.2 Gas Processing and Sulfur Recovery Plants

Gas processing and sulfur recovery schemes must be approved by the Board prior to any construction related to the scheme. In instances where the gas is to be processed for the removal of hydrogen sulfide an application for approval must be considered at a public hearing or a notice of the application must be published so that objections may be filed with the Board.

The regulations describe in detail the information needed in support of an application for approval of a new gas processing scheme. With respect to pollution control, the main items required are evidence in support of the proposed sulfur recovery level, a discussion of the reasons for the choice of the plant location, evidence that the main emission and emergency flare stacks have been designed to maintain the maximum half-hour average ground level concentration of sulfur dioxide within acceptable limits, detail respecting the proposed air quality monitoring system, the proposed methods for control of hydrocarbon vapors and sulfur dust, and proposals respecting disposal of produced and process water.

Operators of processing plants treating gas for removal of water are required to report monthly to the Board certain operating data including daily volume of sulfur emitted to the atmosphere as sulfur dioxide. Where the daily emissions of sulfur exceed the quantities approved by the Board, the operator is required to immediately correct the situation. This places day to day responsibility for adherence to emission standards directly with the operator of the plant, because the sulfur recovery efficiencies required of gas processing plants are normally enforced over three month periods and therefore represent three month average recoveries. The sulfur recovery on any one day may be considerably less than that required as a three month average. The daily operations of the plants are controlled primarily through sulfur dioxide emission limitations and in some cases through continuous atmospheric monitoring.

Recent amendments to the Oil and Gas Conservation Act require the Minister of the Environment to assume responsibility for final approval of the environmental aspects of all gas processing operations, including the underground storage of gas. In this way environmental decisions issued by the Board are subject to prior confirmation by the Minister of the Environment.

REFERENCES

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PART 5

RECOGNIZED AIR POLLUTANTS, THEIR DISPERSAL AND DETECTION

5.1 Introduction

We have seen that the Energy Resources Conservation Board devises, issues and enforces regulations designed to maintain pollution levels which are set principally by the Department of the Environment - or more stringent standards if the Board so prescribes. The appended Air Quality Standards (Appendix 1) prepared by the Air Pollution Control Section of the Department of the Environment establish the air pollutant limitations as currently applied throughout the province.

The obvious pollutant to begin with is sulfur dioxide, as it is the unavoidable (at present) result of less than 100% elemental sulfur recovery. Furthermore, although hydrogen sulfide is possibly just as obvious, if not more noxious, regulations imply that it should not be admitted to the atmosphere at all. That is, wherever feasible hydrogen sulfide is to be combusted to sulfur dioxide. In so turning our attention to this common pollutant we are led to a consideration of incinerator stack design and subsequent dispersal of the sulfur dioxide issuing from such a stack.

5.2 Stack Design Criteria

In that part of new plant approvals dealing with incinerator stack design and sulfur dioxide emission, such approval is based upon a calculated maximum one-half hour ground level concentration to be expected, given certain simplifying assumptions, from a stack of given height. The sulfur dioxide standards used for stack design purposes are:

(a) 0.20 ppm for a 30 minute averaging period to be used in urban and arable agricultural areas (this implies range land falls into class (b)),

(b) 0.30 ppm for a 30 minute averaging period to be used in all other areas with due allowance made for the height of trees in forested areas, and

(c) 1.0 ppm to be utilized for emergency flaring periods not exceeding one hour in duration.

The sulfur dioxide discussed is formed in an incinerator used for the burning of unrecovered sulfur compounds contained in the tail gas leaving the sulfur recovery plant. This tail gas contains sulfur compounds in the form of hydrogen sulfide, sulfur dioxide, carbonyl sulfide, carbon disulfide, sulfur vapor and droplets of entrained sulfur liquid. To confine emissions to chemicals considered to be least noxious and harmful the tail gas is thus combusted to oxidize all such sulfur components to sulfur dioxide. The additional constitutents of the incinerator gas, as far as they have been analyzed for, are given in Table 3.1, Column 9 for a typical plant.

Since sweet gas (methane) is also added to provide the heating value specified, this analysis should also include the water vapor arising from sweet gas combustion. In this way, the completely combusted tail gases are exhausted to the atmosphere at a temperature of at least 1000°F through a stack of sufficient height to yield a calculated maximum half hour ground level concentration of sulfur dioxide within the prescribed limits for that particular location. Half hour limits are set only to be in harmony with the requirements of the equations used by the Department of the Environment and the industry in establishing acceptable stack heights.

5.3 Meteorology

Pollutants and other plant effluents are carried by the wind and, at the same time, diffuse or intermingle rapidly with neighboring parcels of air. The main causes of this mixing are (1) the eddies and currents occasioned by the shearing motions of the air when it encounters an obstacle such as a building or hill, and (2) vertical exchanges of warm buoyant air (heated by land or water surfaces) with cooler, denser amounts of air that sink down to replace or mix with them. The first effect is the familiar mechanical turbulence which is capable of producing both vertical and horizontal mixing, while the second, known as thermal turbulence, is the major mechanism by which vertical mixing of pollutants takes place. Mechanical turbulence is strongly influenced by the wind speed and terrain roughness, while the prime environmental factor influencing thermal turbulence is the vertical temperature gradient of the atmosphere. When the gradient is such that warmer air overlies cooler air the atomsphere is said to be stable, vertical motion of air particles is hindered, and a temperature inversion is said to exist. When the temperature gradient is reversed, mixing can take place and a situation of instability is said to exist: air mixing or thermal turbulence can take place to alleviate local build-up of high pollutant concentrations. A common situation is one in which an inversion is found 500-600 feet above the surface of the earth, the vertical mixing of pollutants thereby being limited to a thin section of air lying between the ground and the base of the inversion. Local factors that influence the volume of air available for dilution of pollutants include land-sea breezes, mountain valley winds caused by differential heating of the surface, surface roughness, and possible heat radiated from buildings.

Such broad remarks also take cognizance of possible stagnant air masses being pocketed below surrounding hills or similar slow-moving, trapped, air under dense forest cover.

5.4 Air Chemistry of Sulfur-Containing Compounds

5.4.1 Sulfur Dioxide

After sulfur dioxide enters the atmosphere, it is oxidized by one of two pathways to sulfuric acid or a sulfate salt. The first path consists of oxidation to sulfur trioxide (SO_3) with subsequent hydration to form sulfuric acid, which may react further with atmospheric particles to form sulfates. The second path involves uptake of sulfur dioxide by aerosols (an agglomeration of molecules) or dust particles, in or on which sulfur dioxide is catalytically oxidized to sulfate salts. Airborne bentonite soils, such as occur in Alberta, are efficient catalysts in this regard. Oxidation of sulfur dioxide can also occur directly in the hot stack gas in the presence of oxides of nitrogen or metallic oxides. While the direct rate of photochemical oxidation of sulfur dioxide is about 0.1% per hour in unpolluted air, this rate goes up to 10% per hour in noonday sun in the presence of as little as 0.1 ppm of olefinic hydrocarbon plus 0.3 ppm of nitric oxide (NO). In the situations normally encountered in rural Alberta, photochemically induced removal of sulfur dioxide is probably not nearly as important as those mechanisms of heterogeneous catalysis.

In some urban areas, sulfuric acid and sulfates account for 5 - 20% of the total particulate matter in the atmosphere (no data is available for Alberta). These particles come to earth through the action of precipitation (snow, hail, or rain) and by simple coagulation, settling, and absorption at the surface of the earth.

Case studies of convective storms in Central Alberta by the Alberta Hail Studies Group showed that 20 - 60% of the sulfur dioxide entering such storm systems by updrafts through the cloud base is removed by rain droplets and deposited as sulfate in the vicinity of its origin. Even though typical Alberta sulfate concentrations in rain water of 2.0 - 4.0 mg/l are above the world-wide background of 0.5 mg/l, they are still well below the values for industrialized areas of North America. The long term effect of this sulfate accumulation is, however, an increasing matter of concern.

Since convective storms occur in Central Alberta on the average of once every other day, it would appear that in summer most sulfur dioxide is removed before the air leaves the province. This sutiation contrasts radically with that which undoubtedly prevails in the winter. Snow is a very inefficient scavenger of sulfur dioxide, partly because snow is formed as a solid and the low temperatures encountered slow down all physical processes which lead to the incorporation of sulfur dioxide in the snow crystals. In the winter, while 10 - 15% more sulfur dioxide is emitted than during the summer months, its removal mechanisms are appreciably less efficient, and less well understood. Under these conditions the everage lifetime of sulfur dioxide (three to four days) may be such as to finally bring it to earth or to convert it to sulfate at great distances from its source. This subject has received almost no research effort.

5.4.2 Hydrogen Sulfide

Studies have indicated that hydrogen sulfide is rapidly oxidized by the normal ozone background in the atmosphere. This oxidation process is presumed to occur on the particulate matter normally present in the air. Given a reasonable ozone level of 0.05 ppm and an estimate of the particulate concentration in the air, it can be calculated that one-half of any hydrogen sulfide present is oxidized every 5 hours. Many independent confirmations of this half-life have been made. No figures are available on Alberta background hydrogen sulfide levels; on a world-wide basis a value of 0.1 part per billion (0.1 ppb) is estimated.

Other than what has just been mentioned very little is known in detail about the processes which convert hydrogen sulfide to sulfate in the atmosphere. It is a fact that in the laboratory a few tenths of a part per million of nitrogen oxides are capable of photochemically converting hydrogen sulfide to sulfuric acid. Whether this is a reasonable pathway in ambient air is so far speculative.

5.4.3 Other Sulfur Compounds

Like hydrogen sulfide other sulfides such as carbonyl sulfide, carbon disulfide, and mercaptans, also do not absorb energy in the visible spectrum to become activated or dissociated. In the presence of ozone or other photochemically active species, such as nitrogen oxides, they do react in the laboratory to eventually form sulfur dioxide or sulfinic acids, which are themselves the source of eye-irritating aerosols.

While the fundamental chemistry of possible individual atmospheric chemical reactions have been quite well documented in the laboratory, here in Alberta we have only made a beginning into the analysis and fate of the possible constitutents of our atmosphere. In order to give more sophistication to present monitoring information we shall need to know such things as the composition of the particulate matter, concentrations of ammonia, heavy metal oxides, sulfates, and hydrocarbons, all of which have been implicated in health deterioration associated with air contaminants.

5.5 Stack Dispersal to Ground

The ground level distribution of pollutants emitted by a stack varies with the distance from that stack in a complicated way. Generally it would be expected that this concentration would be low near the stack, increase, go through a maximum and then decrease as it recedes from the point of emission. What happens in practice cannot as yet be predicted with any real accuracy. Only generalizations can be made based upon the assumptions inherent in the mathematical formulas used to arrive at an acceptable stack height.

Where the maximum ground level concentration will occur depends in part on the atmospheric stability. During unstable situations (high turbulence), a maximum concentration can be expected near the stack; as atmospheric conditions become more stable, the maximum moves progressively further from the emission point. A general rule of thumb indicates that the maximum ground level concentration occurs 10-20 effective stack heights down wind.

The amount of pollutant recorded at every ground level point is expected to change in the same proportion as the rate at which pollutant is discharged through the stack. Additionally, the formulas used imply that the average down wind concentrations of pollutant vary inversely with the square of the stack height: doubling the stack height will decrease all ground level concentrations to one-fourth of their original value.

The formulas used to establish a proper stack height and pollutant emission rate have a certain amount of physical justification, they are basically just useful approximations. A recent field study in Alberta concludes that the Sutton and Pasquill equations used in stack design normally result in actual ground level sulfur dioxide concentrations that are well within the prescribed allowable limits, but that caution is warranted in cases of extreme topography. Interestingly, this study found little difference between the concentration frequency distribution down wind of the emitting source and data from all other directions. It would, off-hand, be expected that dispersion of pollutant about the plume center-line would fall off quickly.

5.6 Acid Gas Flare

Flaring is normally utilized during plant upset, turn around, or other abnormal plant procedures. It is also used on a continuous basis where the sulfur content of the raw gas delivered to the plant is insufficient to warrant the installation and operation of sulfur recovery facilities, as is the case for twenty-five sour gas plants.

In emergencies resulting in a large release of sour gas to flare, gas plant approvals require the plant operator to burn sufficient sweet gas with the sour gas flared to ensure complete combustion and to provide sufficient thermal uplift to the flared gases to prevent ground level sulfur dioxide concentration from exceeding the limits decreed. Whereas incinerator stacks may be 200 - 500 feet high and 15 feet in diameter, flare stacks are of lesser height and diameter. The empirical calculations employed in flare stack design are very suspect in the author's opinion and should perhaps be the subject of additional research to justify their adaquacy. In the case of incinerator stacks, combustion takes place at the base of the stack and the temperature gradient up the stack must be such that the gases exit at greater than 1000^{0}F. Gases vented to flare stacks, in contrast, are ignited by a pilot light at the flare stack mouth.

While practice dictates that gases to flare must have a heat content of at least 250 B.T.U. per cubic foot, and while in addition, an average flame temperature of 1800^{0}F is assumed, no actual tests of the completeness of combustion have been conducted. In extreme cases of plant upset, it is possible to produce flare stack flames 100-200 feet in height which may be visible for 30-40 miles. For flames of this size and velocity, it is conceivable that due to possible incomplete combustion, at least around the perimeter of the flame, a variety of oxgenated hydrocarbons are passed into the surrounding air. Though, as mentioned earlier, their existance and concentration have not been dealt with, the types of compounds suggested would seem to duplicate those normally implicated in the irritating effects of urban smog.

It is also interesting to observe in this connection that in the Pincher Creek area the Department of the Environment conducted gas-chromatographic analyses of ambient air in the hopes of detecting possible odorous hydrocarbons. Partially oxygenated species such as aldehydes and ketones were not mentioned in this survey, yet they would be logical contenders as possible sources of noxious odors even at very low levels.

5.7 Incinerator Stack Monitors

There is no question that local topography and meteorological conditions can lead to contaminant levels at variance with gross predictions. It is also quite possible under proper atmospheric conditions and high wind speeds for plants to grossly exceed their allowed stack sulfur dioxide concentration without this violation being detected by ground level monitors. Each plant is therefore now required by the Energy Resources Conservation Board to report monthly a complete sulfur balance around their operation to ensure that their prescribed recovery efficiency is maintained regardless of raw gas input rate. This has eliminated the above possibility. In addition, plants are required to have installed some form of continuous stack pollutant monitoring device. These are usually infra-red or ultra-violet photometric sulfur dioxide detectors, though gas-chromatographic systems are also in use. Such instruments, in principal, are capable of instant read-out with a telemetering capability to perform master-slave routines with the front end of the sulfur plant. In fact, de-bugging of this new equipment in many instances is still proceeding, which means that sulfur balances are often made by subtracting from the plant inlet sulfur the amount of sulfur gauged in the pit and calling the difference sulfur incincerated to sulfur dioxide through the plant stack. The accuracy of this method has been questioned in a previous section dealing with calculation of sulfur plant efficiency, therefore considerable effort is being devoted to adapting the monitoring equipment to plant conditions.

5.8 Off-Site Ground Level Monitoring

5.8.1 Exposure Cylinders

Today the usual survey method for sulfur dioxide and hydrogen sulfide is by means of so-called "exposure cylinders". This entails exposing strips of lead dioxide (for total sulfation) and zinc acetate (for hydrogen sulfide) to the atmosphere for a known period of time. Neither reagent is capable of detecting organic sulfur compounds (e.g. mercaptans, carbonyl sulfide, carbon disulfide). It is common practice to use these exposure cylinders to obtain background ambient levels before a sour gas plant goes on stream in addition to their habitual use once the plant begins operation. The cylinders are usually exposed for one month with the pollution figures submitted to the Department of the Environment by the end of the succeeding month, who then relay the information, citing any irregularities, to the Energy Resources Conservation Board.

The number and distribution of such exposure cylinders are determined between the plant and the Department of the Environment. These are then usually serviced either by the plant or a private concern hired by the plant operator. Each of such monitoring stations is considered on its own since each has its own unique micro-topography and meteorological conditions. Thus, it is difficult to compare data from the various exposure cylinder monitoring sites, except as individual sites on a yearly basis. Furthermore, this type of equipment gives only monthly averages and cannot give information about possible occurrences of high local pollutant levels: these are smoothed out over the month. More serious is the fact that exposure cylinder data is presented in a form completely unrelated to the units in which current ambient air quality standards are given (parts per million and micrograms per cubic meter). The ability of exposure cylinders to function properly at our extreme winter temperatures has yet to be determined. It is precisely this season of the year when plants are operating at or nearest to their capacity and would be emitting a maximum amount of pollutants.

5.8.2 Mobile Air Monitoring Trailers

In point of fact, the heart of the monitoring system is considered by air monitoring personnel to be the mobile air monitoring trailers, as these contain the apparatus capable of providing minute-by-minute air quality information in a form which can be translated into the defined ground level limits for hydrogen sulfide and sulfur dioxide. Unfortunately, such trailers are of limited mobility and require a readily accessible source of power. Furthermore, it is only following prior independent definition of a particular site as one of high pollutant concentration that the trailer facility might establish the time dependence of contaminant concentration. Time delays and changing climatic conditions would seem to mitigate the practicality of such units except as where a number of such units were in service simultaneously. The Department of the Environment has two such monitoring trailers, and will have two more by fall, with which to police the entire province. New directives suggest that by 1973, plants of over a prescribed size in sulfur production will be required to possess at least one mobile unit of their own. Since most large sour gas plants already operate such trailers, this order simply formalizes existing circumstances. The cost of a completely equipped trailer runs to $20,000.00. Such equipment includes automatic hydrogen sulfide and sulfur dioxide monitoring instrumentation, wind speed and direction gauges and possible telemetering facilities connected to the interested plant. Whether such trailers operate as efficiently in winter as summer would be worthy of comment.

5.8.3 Sulfur Dust Fall Monitors

As a result of the concern over incidents of soil sterility and reduced crop yields attributed to wind blown sulfur dust, sulfur producing plants are additionally required to maintain sulfur dust fall monitors. The data obtained from these are reported on the same 30 day basis as the exposure cylinders. Since the majority of plants do not ship any more block sulfur (slated sulfur alone is accepted at Vancouver), the specification of these units is somewhat redundant, as the dust problem is of real concern only during breaking and loading of the blocks. However, the problem may arise again because plant operators will have to consider re-melting and slating of the existing blocked sulfur as a possible means of reducing existing stockpiles.

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PART 6

OTHER SOURCES OF POSSIBLE ENVIRONMENTAL CONTAMINANTS

Without bringing into consideration the monumental question of alleged off-site accidents and intermittant plant upsets, there exists a number of waste chemical disposal problems within the normal routine of the plant which deserve mention.

6.1 Process Waste Water and Liquid Chemicals

The Department of the Environment normally maintains jurisdiction over this aspect of plant operation.

Process waste water is often retained and may be treated in large open ponds before being disposed of to a surface body of water, or, if the amount of water is small, before it is allowed to evaporate to the atmosphere. The ponds may also be a source of air pollution due to "weathering" of the wastes contained in them. Substances discharged to such ponds may be any one or all of the following types:

1. Cooling water treating chemicals (phosphates, chromates, chlorine, biocides, sulfuric acid, corrosion inhibitors, etc.).
2. Boiler water treating chemicals (lime, chelates, phosphates, corrosion inhibotors).
3. Sour Water. In those cases where this is not re-injected down a well, it is usually stripped of its hydrogen sulfide before removal to settling ponds.
4. Oils and greases. These normally arise from machinery such as compressors and pumps. Recent plants have completely enclosed drainage systems to prevent such water immiscible substances from entering the ponds.
5. Spent treating chemicals. These would consist of spent caustic or amine carry-over, possibly saturated with hydrogen sulfide. In some cases these chemicals can be incinerated to dispose of hydrogen sulfide.
6. Products of Corrosion. Iron sulfide and sludges are produced or carried through the amine sweetening step and are removed in an amine clean-up procedure, the residue from which usually goes to the settling pond.

The magnitude of the problem caused by the disposal of these wastes depends very much upon the efficiency of individual plant operation, the size of the processing operation and the composition of the inlet gas to the plant. Orders of magnitude can be suggested for some types of waste. One plant estimates it must replace four pounds of amine per million cubic feet of gas processed. For a plant operating on 45 million cubic feet per day, this would imply the need to replace 180 pounds of amine per day. Naturally not all of this represents degradation products or sludge; most of it is carry-over to the Claus units. The amine clean-up units consume around 21 pounds of diatomaceous earth per day in performing their sludge and iron sulfide removing job. This residue normally goes to the settling pond. As another example, a particular plant of 100 million cubic feet per day inlet capacity admits an estimated 3 gallons/minute of waste water and treating chemicals to their settling pond. Another operator periodically dredges the sludge from the bottom of his pond and uses this material to improve dikes around the pond.

Aeration can be employed to oxidize chemicals in the waste water which would otherwise rob oxygen from aquatic life.

6.2 Other Materials Used

Spent bauxite catalyst, molecular sieve and solid drying agents also often require disposal. These waste chemicals do not normally create a source of off-site pollution and can be buried in pits or used as land fill on the plant site. The amounts of catalyst involved again varies. During plant turn around, plants must dispose of or regenerate from 50 to over 200 tons of catalyst. Such turn arounds normally are on a 1-2 year cycle, although shorter periods are not unusual and again depend upon the intricacies of plant operation. Bauxite is an aluminum oxide with a few percent of iron oxide. The inactive spent form contains appreciable water soluble aluminum sulfate. The environmental effects resulting from leaching of this material are unknown. It is not unusual to see spent catalyst spread around the plant site or used as road gravel.

6.3 Vapours, Storage Tanks

Stored pentanes plus can cause pollution by the evaporation and release to the atmosphere of the lighter hydrocarbons and sulfur gases (primarily hydrogen sulfide) in the product. Gas plant approvals require that the product be stored at a vapour pressure less than atmospheric to minimize evaporation loss. In addition, stock tank vapour recovery facilities or stock tank vapour flares are often used but are not mandatory.

6.4 Burn Pits

Disposal of water and hydrocarbons (often containing dissolved hydrogen sulfide and mercaptans) to burn pits can result in a pollution problem. Odors may result from the "weathering" of liquids in the pit and smoke and sulfur dioxide can result if a significant amount of burning takes place.

Normally a continuously burning pilot flame is placed over the point where the wastes flow into the pit to burn any combustible gases evolved. Sulfur dioxide, carbon dioxide and water vapour are the products of this combustion. This is true if combustion is complete. However, the appearance of smoke is a good indicator that combustion is not complete. Under these conditions noxious aldehydes, ketones, mercaptans and similar species can be formed through partial oxidation and thus contribute to air contamination. Sufficient fuel should always be added to ensure combustion is indeed complete. The same reservations (as mentioned for flare stacks) hold for the operation of these burn pit flames.

The quantity of wastes disposed of to the burn pit should be minimized. Closed drain systems are now piped into a liquid hydrocarbon recovery tank rather than flowing to the pit. The liquids from this tank can be pumped back into the plant and the vapours can either be recovered or vented to flare. Liquids entering open drain systems are not as easily recovered. For this reason hydrocarbon liquids and sour liquids should not be allowed to enter the open drain system.

In the field, when a new well is ready to go on stream, it is necessary to first clear from the well all the materials used in the drilling operation.

These can include carbon monoxide, drilling mud, sulfuric acid, hydrochloric acid, hydrogen sulfide, salt water and of course the hydrocarbon in the well. All of this is blown to a 'knock-out pit' provided with flaring facilities. Since the composition of the effluent going to the knock-out pit is not accurately known there is no assurance that it will burn. If it doesn't and the well is an acid gas well some noxious chemicals may be vented in large quantities to the environment.

6.5 Liquid Sulfur Storage Pit Vapours

Hydrogen sulfide dissolved in the liquid sulfur product can be released from such liquid sulfur when in the liquid sulfur storage pits. This gas is normally vented to the atmosphere through a stack on the pit roof. The quantity is normally small and does not usually create a pollution problem although an odor may sometimes be obvious in the vicinity. Where sulfur is transported in tank cars as a liquid, by the time the material arrives at its destination sufficient hydrogen sulfide may have degassed or be degassed during the re-heating of the tank cars to be of serious concern to those persons employed in the unloading operation. In fact fatalities are known to have occurred through lack of precaution.

6.6 Monitoring and the Local Resident

A fair comment would be that the complaints of local residents, coupled with the usual ready compliance on the part of plant operators in reporting incidences of excessive emissions, are the real heart of the present detection system, since this to a large degree initiates detailed investigation by the Board or the Department of the Environment; and such complaints assist in determining the location of the mobile monitoring equipment.

REFERENCES

1. AMD 72-1, 2, 3. Pollution Control Division, Department of the Environment, Government of Alberta, 1972.
2. "Air Pollution Control at Gas Processing and Sulfur Recovery Plants", Alberta Department of Health, 1969.
3. Discussions with individual plant managers.

PART 7

PROPOSED FUTURE ANTI-POLLUTION GUIDELINES AND MONITORING DIRECTIVES

7.1 Anti-Pollution Guidelines

As early as July, 1970 the Energy Resources Conservation Board, in meetings with operators of gas processing plants and through the issuance of recent processing plant approvals, indicated that an increase in sulfur recovery efficiency would be required consistent with current trends in technology and the provincial Ambient Air Quality Standards of September, 1970 (refer to Appendix I). Indeed, with the advent of 2000-4000 LTD sulfur recovery plants, the present maximum of 96% recovery still means 80-160 tons per day of sulfur emitted as sulfur dioxide with no hope of profitable recovery in the future. Accordingly the Energy Resources Conservation Board set out the guidelines given in Table 7.1 For a 2000 ton per day plant this nevertheless permits a loss of 20-40 tons per day of sulfur.

TABLE 7.1

ALBERTA'S MINIMUM SULFUR RECOVERY EFFICIENCY GUIDELINES, ENERGY RESOURCES CONSERVATION BOARD. (REFERENCE 1).

Sulfur in sour gas, Inlet rate long tons/day	Process requirements	Required recovery efficiency (%) for various acid gas qualities		
		Favorable	Average	Unfavorable
1,000 to 4,000	Stack cleanup required	98-99	98-99	97-99
400 to 1,000	Minimal Stack cleanup or equivalent process	96-98	95-98	94-97
100 to 400	Minimum of 3-stage Claus plant or equivalent process	94-96	93-95	92-94
10 to 100	Minimum of 2-stage Claus plant or equivalent process	93-94	92-93	90-92

It would appear at present that these tighter restrictions on sulfur emissions will compel modifications to at least twenty-one of Alberta's sulfur recovery plants. Existing plants will have to meet the new criteria by no later than December 31, 1974. Applications for exemptions from sulfur recovery guidelines if such were to be made, were required by May 31, 1972. Applications for proposed plant modifications must be made before May 31, 1973. While these sulfur recovery rules are strict, they are not as stringent as those of the Texas Air Control Board because Alberta guidelines allow more adjustment for plant size. The Alberta regulations as published do not spell out directly what is implied by Favourable, Average and Unfavourable acid gas qualities. However, operators of affected plants have been advised by the Board by letter, of the category the Board considers the plant to be in.

A comparison of sulfur dioxide air quality objectives of Alberta, Ontario, Canada, and the United States, Table 7.2, shows close agreement among the objectives of Alberta, Ontario and Canada. Further comparisons can be made on the basis of the following information as well. Japan specifies an annual average of under .05 parts per million to be attained in developed areas within ten years. The tolerance is presently set at 0.12 parts per million as the annual average. In Germany the 24 hour average is 0.15 parts per million with the half-hour maximum at 0.29 parts per million. Rumania tolerates a 24 hour average of 0.04 parts per million with peak values of 0.14 parts per million accepted.

TABLE 7.2

SULFUR DIOXIDE AIR QUALITY OBJECTIVES AND STANDARDS, AVERAGE VALUES IN VOLUME UNITS (PPM) NOVEMBER 1971 (REFERENCE 3)

PERIOD OF EXPOSURE	ALBERTA (Standards)	ONTARIO (Objectives)	CANADA (Maximum Acceptable objectives)	UNITED STATES (Secondary Standards)
1 hour	0.30	0.25	0.34	0.50*
24 hours	0.10	0.10	0.11	0.10
1 year	----	0.02	0.02	0.02

*Three-hour maximum

7.2 Monitoring Directives

7.2.1 Continuous Measurement of Incinerator Stack Emissions

Plants recovering more than 100 LTD of sulfur, or those emitting to the atmosphere more than 10 LTD of sulfur, are requested to provide a continuous record to the Energy Resources Conservation Board of the daily quantities of sulfur dioxide and other sulfur compounds present in the stack gases. A deadline of September, 1971 may, by individual application, be extended to September, 1972 in order to give operators time to familiarize themselves with the continuous monitoring equipment (gas-chromatography or infra-red techniques). To date, the plants affected by this directive have had varied success in adapting the available technology to their individual needs. Although the Information Letter released to plant managers indicates that sulfur compounds other than sulfur dioxide are to be looked for in stack gases, it would appear that this aspect is not of critical importance at present; only sulfur dioxide is monitored.

7.2.2 Pollution Control Division, Department of the Environment

As mentioned above, the Department of the Environment looks after off-site monitoring. In this case a single report is submitted by the plant on a monthly basis, containing the following:

(a) Exposure cylinder data.

(b) Explanation for any high cylinder levels.

(c) Map of plant area.

(d) Sulfur dust fall cylinder data (where applicable).

(e) Continuous hydrogen sulfide and sulfur dioxide monitoring data (where applicable).

(f) Explanation for any high hydrogen sulfide and/or sulfur dioxide readings.

(g) Plant operating data. Frequency of wind speed and its direction. Instrumentation operations data.

These items have always been part of past and present operating procedure except for the requirement of sulfur dustfall analyses. In response to the increasing size of the industry and its increased environmental impact, Regional Offices have been opened in Calgary, Red Deer and Whitecourt which are part of the community health program. The staff (one technician and one trailer) of these offices are responsible for the collection of local water samples where their acceptability for consumption has been questioned.

In accord with Energy Resources Conservation Board directives asking for continuous stack monitoring for plants having maximum emission approvals of greater than 10 LTD of sulfur in 1972, the Pollution Control Division has specified that such plants also conduct a continuous off-site survey of sulfur dioxide, hydrogen sulfide, wind direction and velocity. The survey is for a minimum period of one month and should cover the interval around the annual plant turn around (catalyst regeneration). As of January 1, 1973, all plants, except those where a continuous year-round hydrogen sulfide and sulfur dioxide monitoring directive applies, must undertake a continuous type of survey as outlined above. This will require all plants affected to have at least one mobile monitoring trailer as described earlier. Even now some plants have had cause to employ as many as seven mobile monitors simultaneously.

The results of the continuous monitoring of hydrogen sulfide and sulfur dioxide can be telemetered easily and instantaneously to the plant or operate an alarm in the plant control room. The possibility of an alarm system triggered to sound when the sulfur dioxide and hydrogen sulfide concentrations at the mobile station is, say, 50% or 75% of the air quality standard, would allow the plant to instigate corrective procedures before a potentially dangerous situation develops.

An additional very necessary service is also to go into effect. In order to assure uniform laboratory procedures a common reference lab will be set up in Edmonton. Individual labs analyzing hydrogen sulfide and total sulfation cylinders will be requested to send one of each kind of exposure cylinder to this Edmonton clearing house for confirmation. A similar service is also contemplated to regularly standardize continous monitoring equipment.

With the advent of sophisticated laser technology and sensitive infra-red radiation detectors, it is now quite feasible to obtain information on the chemical composition of smoke plumes and the health of vegetation by airborne remote sensing instrumentation. Such equipment has in fact been offered by the Federal Government to the Alberta Department of the Environment at a minimal charge. No decision has been reached in this matter as yet.

Water analyses now routinely include testing for a number of potentially harmful trace metals, among these are mercury, selenium, cadmium and lead. Unfortunately the present staff of the Water Pollution Branch of the Department of the Environment consists of one engineer and four technicians. It is hoped to increase this to three engineers, two biologists and eight technicians within the year.

7.3 Pollution Inventory

Early in 1972 the Energy Resources Conservation Board was requested by the Minister of the Environment to initiate a pollution control and occurrence survey into the various phases of the energy resource industries which are specifically administered by the Energy Resources Conservation Board. This inventory is to include the statistics up to June 30, 1972. Such an accounting will include those aspects of pollution occurence and control listed below. (Inquiries as to the date of availability should be directed to the Board).

1. A statistical indication of the size of the industry, to be used in future inventories to make suitable allowances for growth in the base.
2. The sources and types of pollutants.
3. Measurements of pollutants and their effect on the environment or the community.
4. A review of the current pollution control requirements and standards.
5. A statistical indication of the degree of enforcement, e.g. frequency of inspections, results of the inspections, comments regarding methods of enforcement.
6. A review of the unsolved pollution problems and the steps being taken to solve them.
7. A summary of the general condition of this phase of the industry.

The type of information to be derived from the survey in the areas of interest to this report are detailed as follows:

A. Producing Wells and Batteries

1. Basic Statistics: Number of wells and batteries, oil production rate, sour gas production rate, average and range of hydrogen sulfide percentages, salt water production rate.

2. Pollution Sources: sour gas emissions, oil and salt water spills, smoke, odours, noise, weeds, excavations, etc.

3. Effects Noted or Reported: Paint discoloration, rust, vegetation damage, water taste, visual, analysis, odours, ambient air analysis, exposure cylinder data, verified complaints.

4. Current Control Requirements: tubing, casing, cement, safety valve, fences, signs, stacks, vapor gathering, spill reporting and clean-up, lease maintenance, salt water disposal, pit limitations, production equipment specification.

5. Enforcement: frequency of inspection, total numbers, results coded as to unsatisfactory conditions, action taken to enforce regulations.

6. Unsolved Problems: maintenance of leak-tight equipment in sour and corrosive atmosphere, achievement of tight systems for sour gas, salt water, and oil, odour identification.

7. General Condition of Wells, Batteries and Leases.

B. Drilling Operations

1. Basic Statistics: number of wells drilled per year, general comment on active areas.

2. Pollution Sources: blowouts, mud spills, drill stem test oil, sour gas, engine oil, rig wastes, engine noise, drill stem test noise, mud disposal.

3. Effects Noted or Reported: noise, odour, vegetation damage, stream pollution.

4. Current Control Requirements: over water and near water drilling, sump location and construction, blowout prevention equipment and practices, casing and cementing, Department of Lands and Forests requirements, site clean-up, mud disposal, well abandonment programs.

5. Enforcement: frequency of inspections, total number, results coded as to unsatisfactory conditions, action taken, (inspections by other agencies, e.g. Lands and Forests).

6. Unsolved Problems: mud disposal, lake shore and stream bank protection, park and wilderness areas compatibility.

7. General Condition of Drilling Operations.

C. Gas Processing Plants

1. Basic Statistics: number of plants, number of plants processing sour gas, plant throughput and production of various products, total hydrogen sulfide inlet to plants, range in hydrogen sulfide content of inlet gas, per cent of inlet gas flared, total sulfur emitted to the atmosphere.

2. Pollution Sources: flaring of hydrocarbons, venting of hydrocarbons to atmosphere, regular sulfur dioxide emissions, emergency flaring of sour gas, emergency emissions of sour gas, sulfur dust, burn pit, liquid sulfur vapours, liquid sulfur pouring or loading, produced water, process water, smoke, odours, noise, metals in flared hydrocarbons, spent chemicals, sour water stripper vapours, glycol regenerator vapours, other plant waste.

3. Measurement of Pollutants and Effects Noted: measurement of emissions, offsite monitoring and exposure cylinder results, complaints of respiratory ailments, dizziness or black-outs, headaches, odours, noise, livestock illness, damage to crops, rust, paint discoloration.

4. Current Requirements: Regulation requirements including approvals prior to construction, requirements for hearing or notice, ground level standards, measurement of stack emissions, burning hydrogen sulfide to sulfur dioxide, filing of emergency procedures sulfur balance reports, smoke control requirements; requirements specified in approvals

including maximum raw gas inlet rate, maximum hydrogen sulfide inlet rate, conservation standards, maximum sulfur dioxide emission rate, minimum incinerator or flare stack heights, minimum stack emission temperatures, restrictions to flaring, continuous burning pilot, addition of make-up fuel gas, minimum number of stack surveys, minimum net work of pollutant detection equipment, pentanes plus vapour pressure requirement, sulfur dust control, adequate storage and loading facilities.

5. Enforcement: frequency of plant inspections, results of inspections, action taken, frequency of stack surveys, amount of Government monitoring, action taken related to surveys and monitoring, review of production reports for recoveries, review of sulfur balance report, results of report reviews, action taken.

6. Unsolved Problems: higher sulfur recovery efficiencies, stack emission measurement, relation of stack emissions to ground level concentrations, sulfur dust, ground level emissions of pollutants, smoke control.

7. General Condition in Gas Processing Plants in the Province.

D. Oil and Gas Pipe Lines

1. Basic Statistics: miles of various sizes and types of pipe line, throughputs of various types of fluids (map to show locations).

2. Pollution Sources: oil or sour gas from leaks and breaks, surface disturbance, salt water spills.

3. Effects Noted: vegetation damage, temporary air or water pollution, reduced soil productivity.

4. Current Control Requirements: design, construction, spill clean-up, safety valves, signs.

5. Enforcement: inspection frequency, total inspections, action normally taken to enforce requirements, testing.

6. Unsolved Problems: leak detection, corrosion forecasting, spill containment, river crossings, muskeg oil spill clean-up.

7. General Condition of Pipe Line Construction and Operation.

E. Pipe Line Terminals, Storage and Compressor Stations

1. Statistics: number, storage capacities, throughput, location (map), horsepower installed.
2. Sources & Types of Pollutants: hydrocarbon vapours, station wastes, engine exhausts, noise, blow down or bleed-off points.
3. Effects Measured or Reported: complaints, ambient air analyses, vegetation damage.
4. Control Requirements: ground level concentration standards, noise levels, housekeeping, waste water standards, vapour conservation.
5. Enforcement: virtually nil, (inspections planned before June).
6. Unsolved Problems: to come out of inspections.
7. General Conditions.

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5. Bohme, V.E. Energy Resources Conservation Board Pollution Inventory May 8, 1972.
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7. AMD 72-1, 2, 3, Pollution Control Division, Department of the Environment, Province of Alberta, 1972.

PART 8

TAIL GAS CLEAN-UP

Any discussion of the possible justification for the turn to stricter ambient air quality standards not only in Alberta but throughout the northern hemisphere has been studiously avoided in this presentation. There is no question that the energy consumption of industrialized countries is expanding at a phenomenal rate and is expected to do so into the predictable future. Indeed if pollution limits were not made stricter now, then future generations would not benefit from those facets of our rising technological capabilities, which would seem to suggest that industrial adherence to more exacting emission standards are distinctly possible now.

8.1 Cost

The new sulfur recovery guidelines set forth by the Energy Resources Conservation Board and presented in Table 7.1 do not relate to off-site ground level standards; only to the degree of sulfur recovery and the emission of unrecovered sulfur from the incinerator stack. One can see some possible legal basis for controlling emission at the stack mouth when it is realized that at this point pollutants leave the plant site. Additionally, experience shows that transgression of off-site ground level standards are almost impossible to prove with respect to cause and effect.

The new guidelines on sulfur recovery efficiency will require that of the forty or so sulfur recovery plants twenty-one will require varying degrees of upgrading in their recovery facilities. This will involve expenditures up to $5 million for some individual plants, with total cost to the industry of upward of $34 million: What is involved?

Referring to the guidelines in Table 7.1, plants falling in the bottom two categories (perhaps twelve plants) will probably require installation of an additional Claus catalytic converter stage. It is estimated that this will cost $150,000 for a 100 LTD plant and about $250,000 for a 300 LTD sulfur plant. The large extraction plants in the top two categories will have to stand the bulk of the costs, for these plants will undoubtedly be forced to consider some form of Claus unit tail gas clean-up facility. This route will be less costly in the long run than adding additional Claus units which are just incapable of providing the recovery efficiency to be imposed upon the thousands of tons per day plants. For plants hoping to go from 96% to 98% sulfur recovery the cost for a tail gas clean-up facility could be close to $1.6 million in a 1,000 LTD plant. To achieve 99% recovery will cost the same plant in the vicinity of $2.6 million.

Figures 8.1 and 8.2 (reference 6) summarize various estimated costs of providing operating facilities for the removal of residual sulfur from conventional Claus units. These costs are high. Estimates derived from these graphs correlate well with other independent sources.

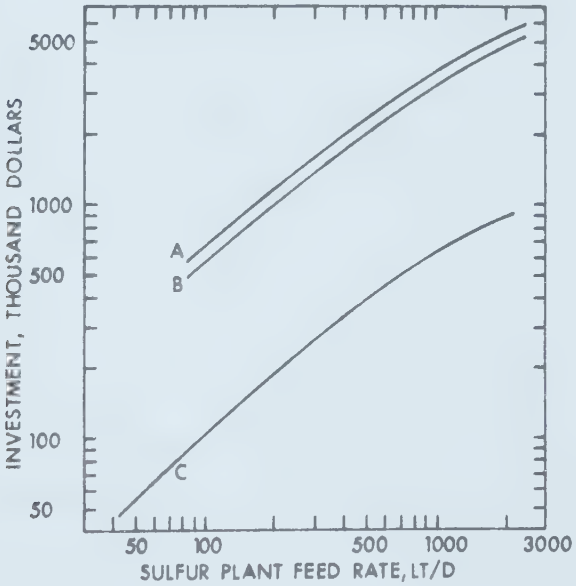

FIGURE 8.1 - INVESTMENT FOR RECOVERY FACILITIES BEGINNING WITH A CLAUS PLANT OF 95% SULFUR RECOVERY:

A. Recovery increased to 99.9%

B. Recovery increased to 99%

C. Add another Claus converter to increase recovery to 96%

(Reference 6)

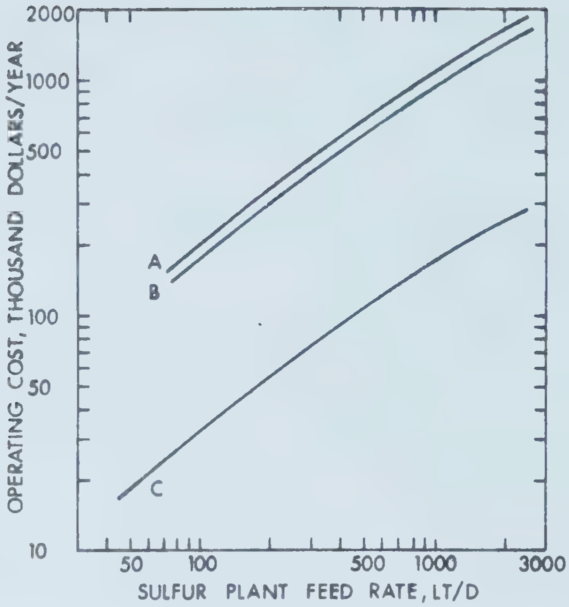

FIGURE 8.2 - OPERATING COSTS FOR RECOVERY FACILITIES BEGINNING WITH A CLAUS PLANT OF 95% SULFUR RECOVERY. A, B, C AS FOR FIGURE 8.1. (Reference 6)

While present recovery limits and their related sulfur emission levels may seem stringent to the industry, this is really an economic limitation and one we, as consumers of energy, must face on somewhat the same grounds. World-wide it is estimated that sour gas processing operations emit 3,000 - 6,000 tons of sulfur dioxide per day. Presently available technology is capable of reducing this to 10-20 tons per day if consumers of gas are willing to pay the costs (reference 7). The economics are such that the costs of environmental protection will not be borne by the additional product recovered, especially at the already depressed price of sulfur. Thus, the current 96% sulfur recovery efficiency has been, relatively speaking, easy. But to carry this from 96% to the 99% presently expected, then to the imperative 99.9% if future prognostications are reliable, will be a real test of the price we are prepared to pay to ensure at least a status quo in environmental quality.

Gas fields don't last forever. Several operators interviewed estimate about 15-20 years as the life of their operating fields. As no new sour gas fields have been discovered in the past three years, and therefore no new gigantic plants are in the offing, the introduction of radically new processes in sulfur recovery is unlikely. Rather, add-on Claus unit clean-up facilities will likely be the short-run answer to more stringent pollution legislation in this province.

8.2 Tail Gas Clean-up Methods

It is to be stressed that the conventional Claus process used in Alberta is capable of bringing stack sulfur dioxide concentrations down to only 5,000 - 20,000 ppm even under the best of conditions. This is going to be 10-100 times higher than acceptable levels. Added Claus units cannot raise conversions to the 99.9% needed to comply with future trends. One solution often proposed hinges on pumping the tail gas into empty wells. This would eliminate the entire problem. After sulfur removal the tail gas is at approximately atmospheric pressure. The size of compressor facility required to bring the gas up to proper pressure for reinjection is said to be economically and auditorily not as reasonable as a first thought might indicate, although helium is currently stored underground in the same way as proposed here for hydrogen sulfide.

In a consideration of possible tail gas treatment schemes one must be aware of the low concentration of hydrogen sulfide and sulfur dioxide which require treatment to yield the desired stack concentrations of sulfur dioxide. For example, acid gas of 85% hydrogen sulfide entering the sulfur recovery facility will be reduced to 1-2% sulfur dioxide (10,000 - 20,000 ppm) in the incinerator stack (See figure 8.3). This is the consequence of reactions producing elemental sulfur, the use of air in combustion rather than pure oxygen, and the volumes of water vapor and carbon dioxide produced in the various combustion processes.

Although a tremendous amount of technical literature exists covering some fifty-odd feasible methods of recovering sulfur present at low concentration, the most succinct and lucid review of the problem and its available solutions has been brought forward by Dr. J. B. Hyne of the Alberta Sulfur Research Institute.

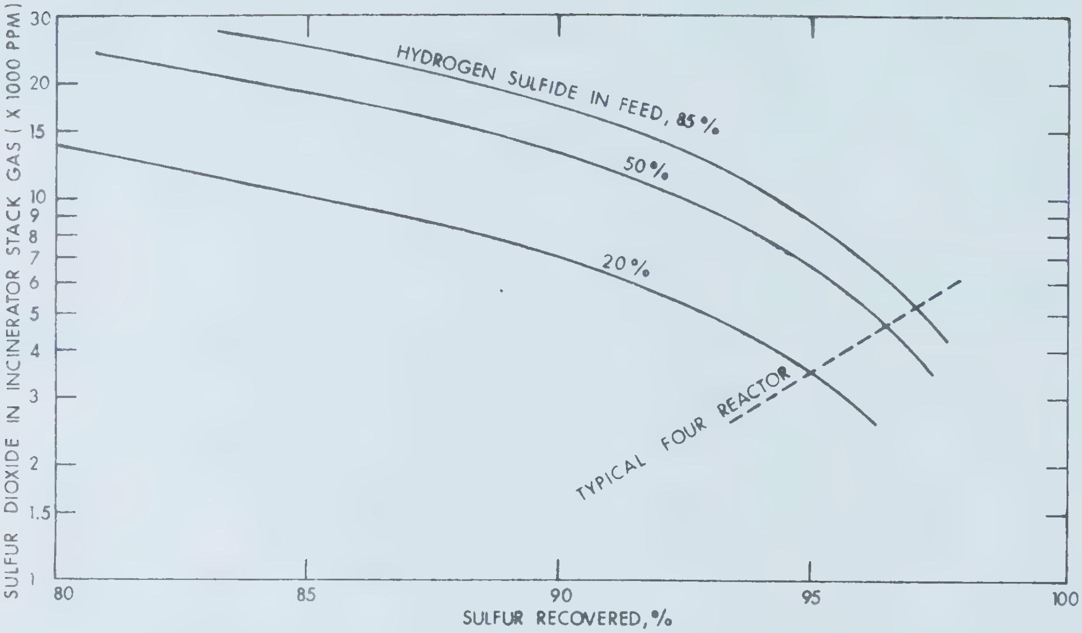

FIGURE 8.3 - SULFUR DIOXIDE IN INCINERATOR STACK GAS VERSUS PERCENT OF SULFUR RECOVERED (Reference 6).

Of the fifty or so processes so far suggested about twenty may be considered seriously for local application. The majority of these twenty involve a reaction between sulfur dioxide and hydrogen sulfide in either a liquid medium in the presence of catalyst or the same reaction occuring principally in the gas phase (Reference 2). The Ram River Aquitaine Plant presently utilizes one of these processes, the so-called Sulfreen process, which makes use of the high catalytic activity of active carbon or alumina, to bring about the hydrogen sulfide - sulfur dioxide reaction needed to recover additional sulfur. Another recent installation in an Alberta plant at Nevis operates upon the same hydrogen sulfide - sulfur dioxide reaction, but in a glycol solvent with the presence of a catalyst (IFP process). Each of these is purportedly capable of sulfur removal to 1000 ppm. In practice, about 4000 ppm is about the lowest level attained by the IFP process at Nevis.

Another process for tail gas clean-up has been announced recently (reference 8) by the Alberta Sulphur Research Limited, an industry-supported sulfur research group at the University of Calgary chemistry department. This method, presently developed only at the laboratory level, uses dimethyl sulfoxide to convert the hydrogen sulfide and sulfur dioxide to sulfur. It has the advantage of also being able to convert carbonyl sulfide and carbon disulfide to sulfur. The use of this new process by the industry will now await further testing at the pilot plant stage.

8.3 Limitations to Clean-Up Procedures

None of the currently feasible procedures is capable of converting carbonyl sulfide and carbon disulfide (600 - 1000 ppm in the tail gas) to recoverable sulfur. If and when stack mouth sulfur levels approach 100 ppm the removal of these contaminants will be critical.

These sulfur recovery techniques are not a complete remedy. Each case will have its own kind of waste product, spent chemicals and disposal problems, not to mention the question of waste water disposal resulting from either the heating or cooling of Claus tail gas to make it compatible with the temperature requirement of the clean-up technique. In addition many of these add-ons require close control of the various process variables to match the more sophisticated chemistry involved.

It is apparent that the choice among more than twenty feasible clean-up additions will set a hard economic exercise for the individual plants. The following factors will have to be considered.

a) A process suitable for a 300 LTD plant may not be so for a 50 LTD plant.

b) The efficiency of a clean-up procedure is intimately linked with that of upstream units.

c) Cost sensitivity of the various processes to the feed composition must be considered.

d) Product (most often sulfur) and waste disposal including thermal pollution is a balancing factor.

Returning once more to the Alberta scene, companies here feel they should have more time to evaluate the clean-up processes used at Ram River and Nevis before being forced into a premature decision on equipment. They point to the fact that the knowledge gained in the operation of the Sulfreen unit at Stage I of the Ram River operation has led to reduced costs in Stage II construction. The IFP process has also been troubled with by-product waste disposal problems which lower its esteem.

Faced with the Energy Resources Conservation Board sulfur recovery guidelines a plant may feel that it has reached a sufficient stage of obsolesence that it would be uneconomic to continue operation if a substantial new expenditure is involved. It may be possible for some plants presently considered deficient in regard to the guidelines pertaining to their particular plant capacity to cut back production, thus dropping themselves to a lower category. This may allow them to continue operating without any major expenditures for capital equipment.

While the envisaged outlay of $34 million for capital equipment is high, the Municipal Taxation Act may provide a possible tax exemption for such equipment used for general pollution control and abatement (reference 5). It has been recommended that these exemptions from taxation include the following:

A. Batteries

  1) Flare stacks and incinerator devices for smokeless burning.

  2) Formation water disposal systems. Tanks for waste material disposal.

B. Gas Plant

  1) All facilities used to remove carbon dioxide and hydrogen sulfide from the inlet stream, waste amine and disposal systems.

  2) Salt water handling and treating facilities.

  3) Sulfur recover plant incinerator stack and monitoring equipment and any equipment for incremental sulfur recovery beyond that for economic operation.

It may be pointed out that federal incentives for pollution control and/or abatement also exist under the Department of Regional Economic Expansion and the Central Mortgage and Housing Corporation. In some situations a more rapid rate of capital depreciation is allowed on pollution abatement equipment. What concessions are made in this area are strongly dependent upon the particular objective(s) to be encouraged.

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PART 9

AIR QUALITY AND HUMAN HEALTH

9.1 General Remarks

In this section it is not proposed to directly provide a rationale for the current Alberta air quality standards. Nor is it possible to exhaustively examine the monumental literature on toxic industrial materials. Rather, it is hoped to make some generalizations about the most obvious pollutants associated with sour gas processing plants and to develop some sort of overview to the common concern for what may be thought of as the crux of the gas plant problem.

The basis of present primary environmental quality standards is the direct effect of pollutants on human, animal and green plant vitality. That is, health effects are represented in these standards only to the extent that a particular chemical can be shown to be harmful to human health. A margin of safety is then added. It is not likely, however, that constantly changing human bodies can respond to changes in their environment in such simple fashion. Such a concept cannot take into account the varied effects on people of different combinations of hazardous substances, the synergistic effect (whereby a combination of hazards produces an effect greater than their individual sum) and the effect of changing weather conditions as they influence the behaviour of a potential pollutant. Nor do these standards take account of the reinforcement attendant upon a pollutant reaching a person from various pathways. Fluorides and lead are examples of substances which can be transmitted through the air and other environmental pathways (e.g. water) as well. More attention is also given to the short-term high exposures to a harmful substance than to its continuous low-level effect. Granted, the latter are most difficult to document, especially in our highly mobile society.

The degree of sophistication required of the monitoring potentialities represented by the above point of view is far beyond our present capabilities. However, while crude surveys of dustfall, total particulate (irrespective of its chemical composition) and sulfur dioxide may be a general indication of the quality of a particular environment, they are not enough. Such an approach can lead to questionable cause and effect relationships between the increased incidence of a particular medical complaint and the presence of higher levels of these two pollutants. A recent study found that in order to get accurate indications of community exposure to sulfur dioxide, four monitoring stations per square mile would be required. If we were to specify these to be of the continuous monitoring type the expense would be considerable.

There is little doubt that increasing levels of toxic materials are bad for human health. There is, however, considerable doubt as to what extent these materials must be curbed to guarantee minimum future suffering. For no pollutant has a threshold been satisfactorily demonstrated, medically. For example, for radioactive substances and ozone the evidence _against_ the existence of a level below which no harm occurs has prompted certain international bodies to warn of risk at any level.

We are not likely to obtain definite answers to questions such as how many more cases of bronchitis are caused for each additional ppm of sulfur dioxide. It is likely, though, that reducing the amount of sulfur oxides and many other harmful additives in the environment will result in improved health. Of all known pollutants only a few trace metals are known to be essential to the human body.

9.2 Individual Chemicals

In discussing the effects upon humans of particular pollutants, one must differentiate, if possible, between short high level effects and the long term low level symptoms. For example, a short high level of carbon monoxide can kill while at low levels visual acuity and loss of an appreciation of relative brightness as well as auditory discrimination are the usual symptoms. Another modifying statement is the difficulty in relating symptoms to their cause. Different pollutants, or indeed sources unrelated to environmental contaminants, can lead to comparable symptoms. It can take an expert medical diagnosis to pinpoint the origins of medical complaints. Headaches and stomach upset are very common symptoms.

9.2.1 Sulfur Dioxide

A 1969 study concluded 0.1 ppm sulfur dioxide over a 4 day period caused irritation only to sensitive people while 0.25 - 0.3 ppm sulfur dioxide caused a big jump in human susceptibility. Currently, the American Conference of Governmental Industrial Hygenists has established 5.0 ppm sulfur dioxide as an acceptable threshold for healthy persons exposed for an 8 hour period 5 days per week. This is well above the sensitivity threshold for green plants and also above the odor threshold of 3 ppm. Concentrations of 0.3 - 1.0 ppm can be detected by the average individual possibly by taste rather than odor.

The immediate effects of sulfur dioxide below a few ppm are negligible to most people. One ppm for 5 hours can cause bronchospasms in sensitive people, however, 400 - 500 ppm is immediately dangerous to life and 50-100 ppm is considered the maximum exposure for periods of 30 - 60 minutes.

Sulfur dioxide is rapidly absorbed by the nasal mucous membranes and thus interferes with the ability of the nose to expel unwanted substances. This action leads to breathing impairment. Sulfur dioxide also enters the lungs through the mouth and is absorbed on fine particles that are carried into the broncheoles. This gas is also dangerous to the eyes, as it causes irritation and inflammation of the conjunctiva.

9.2.2 Sulfuric Acid and Particulate Sulfate

Under certain atmospheric conditions sulfur dioxide has the potential to be oxidized to sulfuric acid or particulate sulfate both of which have their own toxicological effects.

Repeated or prolonged inhalation of sulfuric acid produces the same symptoms leading to chronic bronchitis as does sulfur dioxide. Normally 0.125 to 0.50 ppm may be annoying. The importance of this potential contaminant has not been assessed in the vicinity of sour gas plants.

Sulfur dioxide is easily absorbed and oxidized upon airborne particulate matter to form complex inorganic compounds of sulfur. Laboratory experiments indicate that if a given amount of sulfur in the form of sulfur dioxide causes a 15% increase in breathing resistance, then the same amount of sulfur as sulfuric acid can cause a 60% increase in breathing resistance. Furthermore, if the sulfur were converted to zinc ammonium sulfate particulate of 0.3 micron diameter a 300-fold increase in breathing resistence can be expected. Even though these experiments were performed on guinea pigs, the results indicate that response to pure sulfur dioxide is not a proper basis for consideration of its role as a pollutant since the sulfur toxicity of various compounds does not appear to be simply additive. Put another way, the factor of importance brought out by this research is whether the response to sulfur dioxide, in this case, can be intensified by its inclusion in an aerosol particle as sulfate or by its solubility and conversion to sulfuric acid in rain droplets. The answer would seem to be affirmative for either case.

9.2.3 Hydrogen Sulfide

The present air quality standards prescribe 0.005 ppm as the acceptable background level for hydrogen sulfide over a twenty-four hour period. It has further been specified that all hydrogen sulfide should be converted to sulfur dioxide before admission to the environment, as sulfur dioxide has a higher odor threshold than hydrogen sulfide. No other stated reason can be found. The scientific literature is confused as to what level is detectable by the human nose; values of 0.03 ppm and 0.78 have been suggested, the former being the same as the current one hour standard. Fifty ppm is said to cause severe eye irritation, 100-150 ppm paralyses the olfactory senses and 700-800 ppm for 30 minutes will result in death. The toxicity of hydrogen sulfide approaches that of cyanide. Its mode of action is similar. Hydrogen sulfide and other sulfides act by fixing the iron in cytochrom A_3, thus reducing the subject's ability to take up oxygen. This leads to paralysis of the respiratory centre. As with carbon monoxide poisoning, sublethal doses are reversible as artificial respiration and oxygen therapy can restore normal breathing. The symptoms are nausea, dizziness and headache. Repeated exposures to low concentrations of hydrogen sulfide (unspecified) lead to conjunctivitis, pain in the eyes and blurred vision.

Again, the American Conference of Government Industrial Hygenists accepts 10 ppm hydrogen sulfide as the threshold level, which is that level below which no health impairment is expected, for an 8 hour working day. In this context it is well to recall the same group suggests 5.0 ppm as a similar level for sulfur dioxide.

9.2.4 Other Substances

Hydrogen sulfide and sulfur dioxide are the principal malefactors associated with sour gas processing plants. Pinpointing less obvious deleterious compounds will require further investigation. Many complaints have been made of unpleasant odors in the vicinity of gas plants not attributable to sulfur dioxide or hydrogen sulfide. Attempts to isolate the responsible chemicals is an arduous task and so far has had little success. Among the possible pollutants (or groups of chemicals) which have already been associated with the operation of sour gas plants are the following:

9.2.4.1 Carbonyl Sulfide (COS)

In high (unspecified) concentration considered to be a narcotic. May produce hydrogen sulfide, sulfur dioxide or even mercaptans and other sulfur containing compounds upon decomposition in the presence of organic vapors.

9.2.4.2 Carbon Disulfide (CS_2)

A threshold limiting value of 20 ppm for an 8 hour day and 40 hour week is specified. Above this value extremely toxic leading even to insanity and personality changes.

9.2.4.3 Selenium

Selenium in small amounts is essential for normal growth and health of some animals. As an element it has a low toxicity. Where the element is chemically combined with organic residues greater toxicity may result because of the higher vapor pressure of organoselenium compounds.

9.2.4.4 Lead

Lead poisoning is one of the commonest of occupational diseases. Lead is a cumulative poison. Increasing amounts build up in the body until eventually symptoms appear. The symptoms and toxicology are extensive and well documented. It takes an expert to diagnose. In cases of lead poisoning findings in excess of .07 mg of lead per 100 cc of whole blood are common.

9.2.4.5 Phenols

A threshold limiting value of 5 ppm in air is given. Chronic poisoning following prolonged exposure to low concentrations (unspecified) result in digestive disturbances.

9.2.4.6 Glycols

Most glycols have low volatility and hence present little danger to humans. Severe poisoning can result from drinking glycol contaminated water, for example, from settling or waste water ponds.

9.2.4.7 Heavy hydrocarbons

The toxicity depends on the specific material. Substances such as Benzpyrene have been incriminated as cancer causing agents in urban atmosphere. No limits are available.

9.2.4.8 Mercaptans

Mercaptan is a class name for any of a large group of organic compounds having a very offensive odor and containing sulfur bound to a hydrogen atom. While mercaptans are trace components in raw sour gas, they by no means exhaust the number of possible sulfur containing organic compounds of even lower odor threshold that may also be present in the raw gas. Among others, mercaptans are even re-introduced as odorizers to the sweetened gas before it is allowed into the home.

Since it may be unnecessarily restrictive, perhaps undue attention should not be directed to mercaptans until their involvement as noxious emanations from the processing plant has been definitely proven.

Nevertheless, as an example, a threshold limiting value of 0.5 ppm has been put forward for ethyl mercaptan (ethane thiol).

9.2.4.9 Mercury

As a result of a concern expressed by the Alberta Fish and Game Association at two public hearings in August of 1971, that harmful amounts of mercury could enter the biosphere by the processing of gas which may contain trace quantities of mercury, the Energy Resources Conservation Board initiated a study into the mercury content of Alberta reservoir fluids. Samples of gas, condensate and formation water were taken from several gas and oil pools in the Province. These samples were analysed by the Department of the Environment Pollution Control Laboratory using flameless atomic absorption methods.

Mercury was not detected in most samples analysed. The highest mercury concentrations detected in the gas, condensate and formation water samples were 1.5 parts per billion by weight (ppbw) in gas from the Elkton Shunda formation of the Brazeau River Field, 45 ppbw in condensate from the Beaverhill Lake formation of the Kaybob South Field and 40 ppbw in water from the Viking formation of the Provost field. These maximum detected concentrations are equivalent to approximately 0.1 pounds per billion cubic feet of raw gas, 10 pounds per million barrels of raw condensate and 14 pounds per million barrels of formation water.

If it were assumed that fluids containing these maximum detected concentrations all could occur in one gas reservoir, and that the reservoir would be the source of supply to a gas plant processing 400 million cubic feet per day of raw gas, 10,000 barrels per day of condensate and 100 barrels per day of produced water, the total mercury entering the plant at the maximum inlet capacity would be approximately 0.14 pounds per day. Any mercury emission from the plant would probably be much less than the amount entering since most of the fluids would be contained and would not be released to the surrounding environment.

It is significant to note that in the United States the Environmental Protection Agency (EPA) has proposed that the maximum mercury emission permitted from one plant is 5 pounds per day. This would, the Environmental Protection Agency believes, maintain safe environment concentrations. A Canadian emission standard has not yet been established.

In specific areas such as Pincher Creek some of the above substances have been sought for in air, water and soil samples by various government and private agencies. Their results have been less than unanimous in establishing that a particular chemical was present in the environment at concentrations considered to be potentially harmful to life over even an extended period of contact. The Department of the Environment does not perform tests for any or all of the above potential pollutants on a regular basis.

9.3 In-Plant Environment

So far environmental health has been discussed in terms of the community outside the confines of the gas processing facility. However, one should not overlook the occupational environment of the employees on the lease or in the plant, as the concentration of hazardous chemicals resulting from an accident or plant upset may exceed by orders of magnitude those experienced by the community at large. Health standards assumed for the employee differ considerably from those for the rest of the community. Indeed, threshold limit values of 10 and 5 ppm for hydrogen sulfide and sulfur dioxide, respectively, for an eight hour day, five days a week, seem to bear little relation to the Ambient Air Quality Standards for the province, exclusive of the plant.

In contrast to the network of sulfation cylinders and mobile continuous monitoring devices off the plant site, in-plant monitoring equipment is more qualitative than quantitative. Indicator tubes whose color changes relate to various hydrogen sulfide and sulfur dioxide levels (within 25%) are consulted after plant personnel detect by odor what to them seems an unusually strong smell of hydrogen sulfide or sulfur dioxide. Safety alarms which announce approach to a potentially explosive mixture of hydrogen sulfide and air or hydrocarbon and air may be found in compressor buildings and around equipment capable of setting up static electric charges or generating sparks. Concentrations of hydrogen sulfide or hydrocarbons which constitute near explosive mixtures with air are well in excess of the concentrations considered injurious to human health.

In touring the plant premises it is not possible to ignore the periodic, transitory whiffs of hydrogen sulfide, sulfur dioxide, or other unidentifiable odors which presumably are well below toxic levels. Yet there would seem to be no detection equipment on the plant site, outside the buildings, which would confirm such a supposition. Inside plant buildings breathing hoses are provided, usually enough for two persons, for those cases where it becomes necessary to enter, or work, in an area of extreme hazard. In areas of incessantly high noise ear muffs are made available. Where noise is a problem the facility is generally completely automated and isolated so that operators need only make periodic inspection passes through such buildings.

Again, while the plant normally does not conduct its own noise level surveys on a regular basis, periodic checks are made by the staff of the Energy Resources Conservation Board.

It is not feasible nor reasonable to regulate health and safety on an industry-by-industry basis. This is evidenced in the functioning of the Division of Industrial Health Services of the Province, where regulations are established by diseases, such as lead poisoning, acceptable noise levels of compressors regardless of industry, carbon monoxide levels, etc. It seems to be

Industrial health statistics are normally complicated by the high degree of worker mobility which makes it difficult to keep continuous medical histories. A person's medical history doesn't follow him from job to job. Incidents of job-associated illness are also not traceable unless a claim has been made to the Workmen's Compensation Board.

There is even more cause for being disturbed when it is realized that in Alberta there are only four people trained in industrial hygiene for work within a plant and all of them are in Edmonton. We should feel fortunate, for there are only eleven in Canada. In Alberta there is only one inspector of occupational health and no legislation enabling him to enter company premises except at the invitation of the plant operator or manager.

9.4 Human Factors

The relationships that prevail among individual processing plants and members of the surrounding community are varied and one could easily paint too simplistic a picture of this interdependence, for that in great measure is what best sums up the respective roles - interdependence.

On the one hand evidence of previous grievances and accidents sometimes implants an attitude akin to hysteria in people faced with the realization that a sour gas processing plant is to locate in their vicinity. The plant then bears the blame for every possible mishap, illness or indisposition suffered. There have been instances where success with an initial legitimate complaint against a plant has been the impetus to placing every subsequent problem with field crops and livestock at the door of the gas plant. This has led to a final hopeless resignation such that no further effort is made to maintain farm management.

On the other hand it is also possible to see farmers working land within one hundred yards of sulfur piles or to watch prize-winning cattle and Arabian horses grazing within sight of processing plants. Some may be prompted to thoughts of sheer folly; nevertheless, it is a common occurence. In some instances local people supplement their farm income by working at the sour gas plant, using farm vehicles to get to and from the job. These people provide excellent, though indirect, public relations for plant owners and a buffer between the plant and more opinionated residents.

Plant personnel, on their side, have individually been commendable citizens of their local communities. Some have been instrumental in bringing to moribund central Alberta towns a renewed vigor through participation in such diverse projects as upgrading of local recreational facilities, sitting on local school boards and even writing local histories.

Often, of course, public relations between the local farm community on the one hand and corporate bodies, including government agencies, on the other has not been as good as it could be, mainly, it would seem, because the value of good public relations has been severely under-rated. Many problems and attitudes could be avoided or at least lessened if interactions between these groups had been more direct.

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PART 10

EFFECTS OF POLLUTANTS ON FARM LIVESTOCK

10.1 General Remarks

On a number of occasions in past years veterinarians of the Department of Agriculture have been called upon to assist with investigations of reported damaged to farm livestock thought to be the result of activities associated with sour gas processing operations. Complaints have been of a varied nature depending for the most part on the manner in which the animal encountered the source of toxicity. Where the state of illness has been thought to result from airborne sulfur containing chemicals, the most common diagnosis is one of damage to the lungs (pulmonary emphysema) or irritant damage to the eyes resulting in inflammation and even blindness. Livestock owners insist high local gas concentrations result from unique weather and geographic conditions and in so doing illustrate the importance of episodic events in contrast to violation of any long term air quality prescription. In fact, compensation was awarded to an owner of swine shown in one specific instance to have died as a result of lung damage.

Cases of sulfur spills or blowing sulfur dust in livestock drinking water, animals dying after having access to plant waste effluent treating ponds also have been reported. In numerous instances the cause and effect sequence has been so well proved that recompense is made to the affected party. In still other cases compensation has been made by the plant operator as an apparent token of goodwill to the local inhabitants where injury or mortality could not be directly connected with any gas plant procedure. The prospect of a possible financial settlement from a large plant has played its own role in the attitudes of some local inhabitants.

From these brief remarks it can be inferred that complaints against sulfur plants are many and varied. Definitive diagnoses of injury are hard to obtain, partly because it is so difficult to perform autopsies on enough specimens and quickly enough to positively identify the cause of death. There is indeed a general lack of knowledge about the effects of these various gases, effluents and lubricants upon not only livestock but all members of the biosphere.

As well, some very complex relationships may arise such as the possibility that, as a result of gas plant emissions or for some unrelated reason, local ecology changes: new animal forage or weeds may enter an area, one of which is able to concentrate within its edible parts chemicals from the soil which, when ingested in sufficient quantity, cause livestock mortality or sickness. Such synergistic effects are unforeseen and never considered, yet they do occur and are immensely difficult to track down or predict.

10.2 Research

Several years ago the Veterinary Services Division of the Department of Agriculture and the Department of Health conducted a project which consisted of exposing animals, such as rabbits, guinea pigs, and small domestic pigs, to various levels of hydrogen sulfide and sulfur dioxide, alone and in combination, for varying periods of time. Certain levels were demonstrably harmful and the damage appeared to be restricted to the respiratory system. Data was published by Dr. J.G. O'Donoghue.

A current task of the Veterinary Services Division has as its purpose the evaluation of the incidence of atypical interstitial pneumonia in Alberta cattle with particular reference to gas processing plants. This disease was present in Alberta before gas processing plants were here but an effort will be made to determine if there is a relationship to the geographic area of gas plants. It is a disease which has a seasonal incidence, usually being observed in late August or early September. It has multiple causes, some unexplained, and it seems possible that irritant gases could be involved in some outbreaks.

The element selenium has received wide attention lately, partly, perhaps, because it has chemical characteristics similar to those of sulfur, and may perhaps be present at low levels as hydrogen selenide (H_2Se) escaping from plant operations. Deficiency or excess of elemental selenium is associated with serious disease in livestock. White Muscle Disease occurs in calves and lambs as a result of selenium and/or Vitamin E deficiency. Certain areas in the province are known to have selenium deficient soils. Concern has been voiced as to whether sulfur in the soil could inhibit the uptake of selenium by plants, from which it is made available to the animal. Problems such as these are receiving current research support in Alberta.

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PART 11

POLLUTANT EFFECTS ON VEGETATION

11.1 Pollutants and Vegetation

A number of chemicals commonly associated with polluted atmospheres are required by economically important vegetation for growth when applied at reasonable levels and in the proper form. Plants require a certain amount of sulfur in the form of sulfate taken up through the roots. It is also possible that this sulfur may be taken up through the leaves as sulfur dioxide.

D. L. Massey and P. J. Martin (Edmonton Journal, May 4, 1972) in a study on the role of selenium in plants and animals, suggest that this element is vital to plants and animals and that soils in west central Alberta are potentially selenium deficient. Some forms of vegetation in Alberta have even been found to concentrate selenium in their leaves.

Certain Alberta grey wooded soils have been shown to be sulfur deficient and would benefit by addition of sulfur. The hydrocarbon ethylene (C_2H_4) has been used as a plant growth hormone at low levels.

An additional interesting fact is the lack of visible injury to even the most sensitive plants upon 5 hour exposure to levels of hydrogen sulfide up to 40 ppm! As it is a local problem, not of national importance, the plant toxicology of hydrogen sulfide has not received sufficient attention. Other sulfides such as calcium sulfide, sodium polysulfides, and even elemental sulfur have been used as fungicides and are known to be toxic to green plants especially at high air temperatures.

Notwithstanding these preliminary remarks vegetation, including many valuable crops and timber species, is sensitive to air pollutants. Furthermore, an expert is needed to determine whether indeed a chemical pollutant is involved at all. For example the toxic effects of excessive sulfur dioxide can be closely mimicked by several agents such as chlorine gas, hydrogen chloride, or nitrogen dioxide, not to mention frost, drought, insect diseases and some nutrient deficiencies. It is an unfortunate fact, but just those conditions of sunlight and high humidity which are conducive to plant growth also facilitate plant injury by these various polluting substances.

Plants of different species vary in their sensitivity to pollutants. It can be further remarked that the young actively growing stage for all species is most susceptible to damage. In this regard highly sensitive plants such as alfalfa, barley, clover and rye offer some possibility as indicators of sulfur dioxide. A certain species of lichen has been used in England as a bio-assay. All varieties of pumpkin and squash show markings when no other garden plants are touched.

11.2 Consideration of Individual Pollutant Symptomatology

11.2.1 Sulfur Dioxide

Sulfur dioxide absorbed through the leaves and plant tissue is converted to sulfite which is then oxidized to sulfate, the usual nutritional form in which sulfur is used by the plant. Excessive sulfur dioxide causes the concentration of sulfite to build up. It is because of its reducing potential that sulfur dioxide (or sulfite) is considered toxic to plants. Sulfur dioxide at 0.25 ppm, over a number of hours, causes injury to numerous pine and spruce species. Crop yields are usually not affected unless more than 5 - 10% of the leaf area has been destroyed. Synergistic effects have been observed after two hour exposure to sub-threshold levels of ozone and sulfur dioxide, or nitrogen dioxide and sulfur dioxide, for some species of plants. Although the plants tested are not commonly found in Alberta, it does suggest the possibility for research on species indigenous to the province.

11.2.2 Sulfuric Acid Mist and Sulfate Particulate

There have been few studies to determine whether these substances directly affect plants in nature. Thirty to sixty-five ppm of sulfuric acid for four hours failed to cause injury to alfalfa or sugar beets. These levels of sulfuric acid are presumably much higher than found in Alberta.

11.2.3 Hydrocarbon Phytotoxic Pollutants

Ethylene, while a growth hormone at low concentration (not specified), is cited as 100 - 1,000 times more toxic to plants than higher olefins. Ethylene plays a role in the aging of the plant. One ppm over a seven day period gives a visible response.

11.3 Other Considerations

Specific instances of crop damage in Alberta apparently are limited to a total of 100 - 300 acres in the immediate vicinity of sulfur stockpiles where complete soil sterility attributable to sulfur dust prevents the growth of anything but the hardiest weed. The cause and treatment of this type of calamity will be discussed below. Before proceeding to that subject additional comments have come from discussions with the provincial and federal forestry people. It is reasonable to include them at this point.

Basically, the sour gas industry is considered a clean one by those responsible for the province's "green-belt", that area in the foothills region not suitable for agriculture except perhaps for grazing. The majority of it is public or crown land in the various Rocky Mountain Forestry Reserves. So far no more than a total of about two hundred acres have been involved, notably around well sites where discolored vegetation is to be found. It is within the jurisidction of the Alberta Forest Service to see that abandoned well sites are restored. This does not include the thousands of acres cleared for the actual plant sites.

11.4 The Role of Forestry Agencies

Presently the Canadian Forestry Service is working with Aquitaine personnel at Ram River and the Gulf Strachan operation to measure the physiological effects on a wide range of vegetation which will probably experience a doubling in its sulfur dioxide exposure levels as a result of the proximity of the two processing operations. Coupled with this research effort will be a compilation of all research literature relevant to the effects of various industrial pollutants on vegetation, with specific emphasis on local species.

The Canadian Forestry Service is to add to their staff, nationally, some eighty surveillance personnel as their share in the national effort toward pollution control on forested lands.

The situation is not that encouraging, if one considers the gas transmission from well site to the plant, including the preliminary exploration stages. It has been estimated that about 10% of the Rocky Mountain Forestry Reserve cover has been removed in the development of exploration and seismic lines by the energy industries. The acreages involved per year are said to be approximately equal to the number of acres lumbered commercially per year up to and including 1970.

The Canadian Institute of Forestry (CIF) felt concerned enough for the fragility of our "greenbelt" to file a submission with the Energy Resources Conservation Board in opposition to the then proposed Ram River Aquitaine sour gas plant. While the grounds for this opposition were found to be adequately covered by existing provincial regulations, the cooperation between these companies and the Federal Forestry Department on plant physiology and toxicology studies in the area points to the relevance of the Canadian Institute of Forestry brief.

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PART 12

POLLUTANT EFFECTS ON SOIL

The Provincial Department of Agriculture and the University of Alberta have been cooperating with various gas plants in an effort to combat the sulfur dust problem adjacent to their plants. In most instances the processing plant owns most of the affected land and leases it to local farmers. How and why this is so, and what benefits accrue to plant and farmer are questions which are suggested by this circumstance. The new methods of slating and chipping elemental sulfur will go a long way to alleviating future dust problems. Presently very little loading of block sulfur is going on. Additionally, present levels of sulfur oxides in the atmosphere of central Alberta would seem to be contributing insufficient sulfur to eliminate any present sulfur deficiency which might exist in the area. Snow and rain analyses suggest that between two and six pounds of sulfur (as sulfate) per acre are being deposited annually in Central Alberta. Perhaps as much as ten times more sulfur oxides are taken up by the soil through direct absorption than are contributed by precipitation.

Soil has a remarkable capability to accept and decompose vast quantitities of waste materials. The question of soil pollution is vastly different than air or water contamination. Complex chemical and biological processes, when not over-burdened, can be utilized in the soil to dispose of many common pollutants.

12.1 Formation Water and Chemicals

Oil and salt water spillage during exploration and production of oil and natural gas was a big problem. Salt water effects are more difficult to correct than oil spills. Salt water contains sodium ion which causes soils to deflocculate or lose their structure. Thus, leaching of the salt is a very slow process. Sodium ion is also toxic to plants in high concentration. Most salt water is now pumped to disposal wells.

Installation of central pumping stations results in the abandonment of a number of battery sites. The spilled and burned crude oil around such sites can sterilize land for a number of years. Herbicides used around well sites have sometimes sprayed over to crop land causing localized soil sterility.

12.2 Sulfur Dust

Elemental sulfur dust is generated during sulfur block crushing and loading operations at the gas processing plant. This dust may be blown a short distance downwind, confining soil damage to within approximately one mile of the plant.

In the soil, sulfur dust is oxidized to sulfuric acid at a rate dependent upon the type of soil, temperature, moisture and fineness of the deposited dust. This oxidation process is carried out by certain soil bacteria, which, given the proper conditions, are capable of converting up to 1,000 tons of sulfur per acre per year. Sulfuric acid so produced will acidify most soils to the extent that vegetation is harmed and even dies. Damage to vegetation is usually apparent after two or three years of regular exposure.

Most natural soils in Alberta have pH values from 6 - 8. When soil pH goes below 5.5 aluminum and manganese ions, which are toxic, become available to the growing plant. Hence the concern over sulfur dust.

As an example, about 3 acres had been made completely barren by soil acidification, with an additional 2 - 3 acres acidified to the extent that crop growth was poor. Soil pH in the barren area ranged from 3.1 - 4.6. Crop growth had been absent from the area for 5 - 6 years, with the area only able to support Canada thistle and quack grass. Water erosion had removed much of the topsoil, leaving a soil low in organic matter and of poor structure.

Successful reclamation of this plot and others like it have been achieved through the use of liming procedures to bring the soil to near neutrality (pH 7). For soils of pH 5 and less this has required application of up to 3 tons of calcium carbonate per acre. It has been suggested that upwards to 200 acres have been affected to varying degrees by sulfur dust in Alberta. In the instance cited above cost of reclamation was over $300 per acre, including lime, its application and turning into the soil, and the laboratory analyses of the soils. In some cases the value of the land may not justify such expenses.

Since soils have a great capacity for absorbing sulfur dioxide there is great concern locally that a gradual fall in pH will be observed over the years with the attendant consequences outlined above.

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AMBIENT AIR QUALITY STANDARDS

PROVINCE OF ALBERTA

AMBIENT AIR QUALITY STANDARDS FOR ALBERTA

The purpose of this outline is to establish minimum acceptable standards of ambient air quality to protect the health and welfare of all citizens, enhance and maintain the quality of the Province's air resource and prevent insofar as possible deleterious effects to animals, plants and property.

DEFINITIONS:

(1) **Ambient Air Quality Standard:**

The numerical expression of pollutant limitations in the ambient air to minimize deleterious effects on human, plant or animal life and welfare. The standards consist of two parts — a specified concentration level for a particular air contaminant and the time-averaging interval over which that concentration level is measured.

(2) **Standard Conditions:**

For the purpose of this outline, all measurements and calculations shall be referenced to a temperature of 20°C and a barometric pressure of 760 mm. of mercury, where applicable.

AMBIENT AIR QUALITY STANDARDS

The following ambient air quality standards as tabulated are applicable to all areas of the Province of Alberta unless otherwise indicated. The ambient air quality standards are specified in Table I.

The maximum calculated ground level concentration standards utilized in the air management for pollution control and designated in consideration of the ambient air quality standards are tabulated in Table II. The applicable ground level concentration calculations will be the latest Provincial Board of Health approved calculation methods. Where two or more point sources are located in close proximity the maximum ground level concentration shall take into account the cumulative effect of all sources.

The ambient atmospheric concentrations of all substances not specified herein shall not exceed levels considered deleterious to human, plant or animal life and welfare as established by the control authority.

METHODS OF MEASUREMENT

(1) Air pollutants shall be measured by the method or methods listed in Table III or by any other methods approved by the Provincial Board of Health.

(2) A minimum of three-quarters of the total possible readings for each specific time averaging period, shall constitute a valid representation.

(3) Annual averages shall be determined on the basis of any consecutive twelve month interval beginning on the first day of December.

ABBREVIATIONS USED IN THIS REGULATION

°C = degrees centigrade
cm. = centimeter
coh = coefficient of haze
gm. = gram
hr. = hour
l. = liter
m. = meter
mm. = millimeter
mg. = milligram (10^{-3} gm.)
mi. = mile
min. = minute
mo. = month
ppm. (vol.) = parts per million (volume basis)
ppm. (wt.) = parts per million (weight basis)
sq. = square
μg. = microgram (10^{-6} gm.)

TABLE I
AMBIENT AIR QUALITY STANDARDS

	POLLUTANT	CONCENTRATION UNIT	AVERAGE CONCENTRATION FOR APPLICABLE TIME PERIOD			METHOD OF MEASUREMENT
			1 HR.	24 HR.		
1	FLUORIDES (as HF)	ppm. (vol.)		.0040		Spectrophotometry
		mg./m³		.0033		
	FLUORIDES in forage for livestock (dry wt. as F)	ppm. (wt.)			35.0	Gravimetry
		mg./1			35.0	
2	TOTAL OXIDANTS (as O_3)	ppm. (vol.)	.15	.10	90% of readings per month < .07 ppm. (vol.) (.137 mg./m³)	Spectrophotometry
		mg./m³	.29	.20		
3	TOTAL OXIDES OF NITROGEN (as NO_2)	ppm. (vol.)	.30	.10		Spectrophotometry
		mg./m³	.56	.19		
4	CARBON MONOXIDE (CO)	ppm. (vol.)	60.0		8 hour average 15.0 ppm. (vol.) (17.2 mg./m³)	Infrared Spectrophotometry
		mg./m³	68.7			
5	HYDROGEN SULFIDE (H_2S)	ppm. (vol.)	.030	005		Light transmittance or reflectance
		mg./m³	.042	.007		
6	SULFUR DIOXIDE (SO_2)	ppm. (vol.)	30	.10		Conductivity
		mg./m³	.79	.26		
7	SOILING INDEX	coh	90% of average readings per month < 1.0		Annual Average < .45	Light transmittance or reflectance

	POLLUTANT	CONCENTRATION UNIT	AVERAGE CONCENTRATION FOR APPLICABLE TIME PERIOD			METHOD OF MEASUREMENT
			1 HR.	24 HR.		
8	SUSPENDED PARTICULATES	μg./m^3		100		Gravimetry
9	TOTAL DUSTFALL*	tons/sq. mi./ 30 days			15.0 residential area 45.0 industrial and commercial area	Gravimetry
		mg./cm.^{2}/ 30 days			0.525 residential area 1.575 industrial and commercial area	

*due allowance shall be made for normal background levels

TABLE II
MAXIMUM CALCULATED GROUNDLEVEL CONCENTRATION STANDARDS

POLLUTANT		CONCENTRATION UNIT	MAXIMUM ACCEPTABLE CONCENTRATIONS FOR APPLICABLE TIME PERIOD		LAND USE
			30 MINUTE	OTHER	
1	SULFUR DIOXIDE	ppm. (vol.)	.2		urban and arable agricultural areas
	SULFUR DIOXIDE	ppm. (vol.)	.3		all other areas (1)
	SULFUR DIOXIDE	ppm. (vol.)		1.0 (2)	all
2	HYDROGEN SULFIDE	ppm. (vol.)	01 (3)		all
3	OXIDES OF NITROGEN AS NO_2	ppm. (vol.)	.2		urban
	OXIDES OF NITROGEN AS NO_2	ppm. (vol.)	.3		rural
4	FLUORIDES as HF	ppm. (vol.)	01		all
5	AMMONIA	ppm (vol.)	2.0		all

Footnotes

1. In forested areas due allowance must be made for height of trees for stack height calculations.
2. To be utilized for short period emergency flaring only (less than one hour).
3. Where incineration is feasible, the H_2S must be incinerated to SO_2.

TABLE III
METHODS OF AIR CONTAMINANT MEASUREMENT

	AIR CONTAMINANT	SAMPLING METHOD	SAMPLING INTERVAL	ANALYTICAL METHOD*
1	PARTICULATES			
	Suspended	High Volume Filtering	24 hours	Gravimetric (Air Pollution Measurement of the National Air Sampling Network, 1957-61, U.S. Dept. of Health, Education and Welfare, Cincinnati, Ohio, pp. 6-8, 1962)
	Settleable	Dustfall Jar	30 days	Gravimetric (ASTM D 1739-62)
	Soiling Index	Spot Tape Filtering	2 hours	Light transmittance (Hemeon, Haines and Ide, Air Repair Vol. 3, pp. 22-28, 1953)
2	SULFUR DIOXIDE	Conductivity	continuous	Electrical conductance and ionization
3	HYDROGEN SULFIDE	Spot Tape	1 hour	Light transmittance, lead acetate impregnated tape, (Sensenbaugh, J.D. and Hemeon, W.C.L., Air Repair Vol. 4, p. 5, May 1954)
4	CARBON MONOXIDE	Optical	continuous	Infrared Absorption (Air Pollution, A.C. Stern ed., Vol. 2, pp. 433-434, Acad. Press. 1968)
5	OXIDANTS	Volumetric	continuous	Colorimetric, Neutral Potassium Iodide Method (ASTM D 2011-65). Coulometric, Neutral Potassium Iodide Method
6	OXIDES OF NITROGEN			
	Nitrogen Dioxide	Volumetric	continuous	Colorimetric—Saltzman Reagent
	Total Oxides of Nitrogen	Volumetric	continuous	Colorimetric—Saltzman Reagent
7	HYDROGEN FLUORIDE	Volumetric	continuous, 2 hour or 24 hour	Colorimetric, SPADN Method (Bellacke and Schouboe, Anal. Chem. 30; p. 2032, 1958)

* Subject to revision by the Provincial Board of Health.

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